FACTORS AFFECTING THE GALVANIC REFLEX

BY
ROLAND C. DAVIS

Submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, in the Faculty of Philosophy, Columbia University

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Factors Affecting the Galvanic Reflex

CHAPTER I

THE STATUS OF RESEARCH ON THE GALVANIC REFLEX

During the last thirty years about four hundred papers on the galvanic skin reaction (psychogalvanic reflex) and related electrical phenomena have been published. These have been summarized by Grünbaum (25), Gildemeister (21), and Landis and DeWick (33). In general the papers may be classified into three groups, the clinical, studying the reaction in abnormal individuals, the psychological, seeking to find a connection between a mental state and the reaction, and sometimes between the stimulus and the reaction, and the physiological, investigating the local nature of the response and its connection with the nervous system. Altogether, matters in all these fields are in the greatest confusion, scarcely any statement resting undisputed, a condition forcefully shown by the review of Landis and DeWick.

There are, of course, many reasons why results disagree so sharply, but with so little established it seems as though there must be something fundamentally wrong. The clinical investigations have the advantage of a rather definite, easily observed condition, with which to compare all galvanic reactions. They often suffer on the other hand from the defects of the method, the lack of any large number of cases for experiment and control, and unsystematic procedure. In common with the psychological experimenters on the galvanic reaction, the clinical workers have been interested chiefly in the mental phenomena, and have often neglected to use very good methods of electrical measurement.

Those who attempt to discover what mental state is associated with galvanic reaction set themselves a problem of extraordinary difficulty.

(1) Most work indicates that those mental states accompanying the galvanic response are of the kind less readily observed and hard to describe for lack of adequate language, even though one could observe such a state without changing it.

(2) It is quite likely that the reaction often occurs with no accompanying "mental state" or reportable condition.

(3) Since many mental processes may occur during one galvanic reaction, and since the subject is usually unaware of the reaction, it is very difficult to discover which mental process is nearest connected to the reaction.

Physiological investigations of the reaction have usually been more careful in electrical measurements. Disagreements in experimental results in this field seem to arise from small numbers of observations and lack of experimental control of other variables than the one concerned. Aveling and McDowall (1), for instance, produce evidence that the reflex is a change in blood circulation because resistance of the hand would fall somewhat in the manner of a galvanic reflex when circulation was disturbed by pressure on the arm, but failed to observe that pressure on the arm will evoke a reflex whether or not circulation is changed. Even Gildemeister, in spite of the general superiority and importance of his work, on one occasion drew far-reaching conclusions on the basis of thirty-five reflexes. There is a certain casualness about most of the galvanic reflex experiments which seems to indicate that investigators regard the reflex as a very simple matter which can easily be disposed of before breakfast.

In the presence of this multitude of views regarding the galvanic reflex there is an impulse to conclude that none are correct, that the reflex is nothing, and that psychologists in particular had best give up any interest in the matter. Such an attitude appears unduly pessimistic. In spite of the many claims it is not impossible to decide what is correct on the basis of submitted evidence, or to devise new experiments which will decide. On finding that the reflex is not the concomitant of standard psychological categories, psychologists may be disappointed, but they will still have the problem of what stimuli and what states of the organism evoke it.

Physiological investigations have already yielded a body of facts which may be regarded as established. This is especially true of the work of Gildemeister and his associates. It has been shown that:

(1) Body resistance is less to higher voltages than to lower, is less to a.c. than d.c. and tends to fall with the passage of a current (Galler, 12).

(2) There is no appreciable inductance effect, but considerable capacity (Gildemeister, 22, 23).

(3) The body is more like a polarization cell than a condenser (Gildemeister, 14).

(4) The counter emf of polarization is sufficient to account for a great portion of apparent resistance (David, 4), and polarization occurs rapidly (Strohl, 43 and James and Thouless, 28).

(5) This counter emf diminshes during a galvanic reaction (David, 4).

(6 The galvanic reflex is absent or diminished when measured with alternating current (Gildemeister, 13 and Thouless, 46).

(7) Temperature of the reacting area probably affects the reflex.

(8) The reflex is dependent on the sympathetic nervous system (Schilif and Schubert, 41, and Foa and Peserico, 10).

In 1922 Gildemeister (20) used these researches to construct the theory that some membranes in the skin—presumably in the sweat glands—are semi-permeable, and normally polarized with positive ions on the outside. Passing a current through the skin increases this polarization. When the cell is then excited by a nerve impulse the membrane becomes permeable and depolarized, thus lessening apparent resistance. According to this theory the process of the galvanic response is the same as that of any nerve, gland, or muscle excitation. Earlier, Gildemeister (17) reported some evidence that the galvanic skin reaction is part of a general autonomic excitation. Darrow (3) has reported convincing evidence on this same point. Earlier work by Darrow (2) showed the very close correspondence between the galvanic reaction and the slightly subsequent secretion of sweat, making the localization of the galvanic reaction in the sweat glands extremely probable. On the basis of Gildemeister's theory Jeffress (29) investigated the relation between the reaction with a measuring current (Veraguth's phenomenon) and the reaction without the current (E-effect, Tarchanoff's phenomenon) and concluded as the theory suggested that both are the operation of the same mechanism.

There are a number of rivals to the theory of membrane depolarization as an explanation of the electrical phenomena of the skin. The simplest of all theories seems to be the one

indicated by H. M. Johnson in a popular article (30), that changes of skin resistance are caused by the actual presence of sweat. Einthoven and Roos (8) and Wertheim—Salomonson (49) believe the reflex to consist of two components—pure resistance change plus an emf change. Aveling and McDowall (1) cling to the theory that the reflex is a matter of skin constriction and circulatory changes.

It is clear that results of the kind listed have bearing on the methods of measuring the galvanic reaction, and methods of experimental procedure. They are, therefore, needed before experiments of larger scope are attempted. Yet these experiments from the physiological approach have done more than throw light on methods of measurement. On the basis of its present success one may expect further valuable results from its extension farther inland into the organism, arriving finally at conclusions as general as those sought by the investigators spoken of as psychological.

With the continuance of the physiological and objective psychological approach there seem to be four general lines open for investigation.

(1) The discovery of bodily processes concurrent with the reaction.

(2) The investigation of the relation between the reaction and the organism's condition at the moment of stimulation.

(3) The study of the relations between stimuli and reaction.

(4) Research on the mechanisms of conditioning, adaptation, facilitation, fatigue, etc., by use of the galvanic reaction.

So far most attention has been given to the first line of investigation. Except for a few investigations the last has received almost no attention so far. But since the reaction is so intimately connected with nerve excitation and so similar to it, there is an opportunity to study processes which are otherwise inaccessible, except in preparations, or difficult to measure.

CHAPTER II

TECHNIQUE OF MEASURING THE GALVANIC REFLEX

1. Measuring Instruments

Instruments and circuits used for measuring the galvanic reflex are extremely various. It is quite possible that much disagreement in results arises from improper technique. A critical survey of methods used and requirements for proper measurement of the reflex seems to be in order.

The galvanic reaction measured with a small current is a wave of decreased impedance, approximately constant in its general form. It rises to a maximum (the curve being turned upside down, as is customary) in a time varying between 0.5 and 4 seconds (more extreme values might be found under different conditions) and recedes slowly taking several seconds, or even minutes to return to its original level. (See following sections.) Sometimes this main wave is preceded by a small one in the opposite direction. With a measuring current of 0.1 milliampere, the height of the wave may represent a change whose ohmic equivalent is between 0 and at least 5000. As shown in the following section reactions from any one subject will probably not vary over the whole range.

This wide range makes it necessary to use a measuring instrument whose sensitivity can be varied readily and by known amounts, so that differences of 5 and 500 ohms may be measured with equal accuracy. The range of sensitivities of the instrument depends of course on the current used.

The speed of the change is of an inconvenient order. It is so slow that if it is to be amplified it must be handled as a direct current pulse, which is much more cumbersome to amplify than alternating current. But the change is so rapid that instruments designed for measuring alternating current waves are necessary to secure an accurate photographic record, these instruments being much more elaborate and expensive than direct current measuring instruments.

Most of the investigations published have been performed with the common moving coil galvanometer, the deficiency of which is obvious. Dunlap (6) mentioned the deficiency in 1913 and the dozen or so who have since used the string gal-

vanometer have evidently considered the fault too apparent for comment. The "natural period," the time the instrument takes to reach a true reading when it is prevented from oscillating, is considerably longer in the moving coil galvanometer than the duration of the galvanic reaction wave to be measured. Clearly, then, the maximum deflection of the instrument, or its deflection at any other point, will not represent the position of the actual wave. The galvanometer, in other words, tends to act ballistically, and its readings represent something between the current wave and the quantity of electricity passing through it. This is the same difficulty investigators of nerve action currents have encountered with the string galvanometer, a difficulty best solved by Gasser and Erlanger's (11) recourse to the cathode ray oscillograph.

Gildemeister (18) by mathematical analysis of the galvanometer swing and the wave to be measured believes he has arrived at the amount of distortion occurring to any galvanic reaction. Assuming that the true wave follows the equation $E = C \propto te^{-\propto t}$ (E = height. $\frac{1}{\propto}$ time of rise, t = time, e = logarithmic base,) the amount of distortion depends on the ratio of the period of the galvanometer to the rising time of the wave. Gildemeister's table indicates that when this is 1 the galvanometer reaches .609 of its true reading, and when it is $\frac{1}{10}$, .99. Most moving coil galvanometers have periods varying between 4 and 10 seconds. One Leeds and Northrup instrument has a period of 2 seconds, but at best the situation is bad.

It is Gildemeister's belief that the rise of the wave is a function solely of the temperature of the reacting part of the skin, that this can be measured and correction of galvanometer reading made from his temperature and galvanometer distortion tables. Evidence will be presented to show that this is not the case.

The distortion caused by a milliammeter, which is a fairly rapid instrument, was the subject of an investigation to be reported in the *Journal of General Psychology* (52). Little difference was found between milliammeter readings and oscillograph records. This, a string galvanometer, or other form of oscillograph appears to be necessary for measuring the reaction with suitable accuracy. The oscillograph, of course, has the advantage of making photographic records.

2. The Circuit

The electrical circuit used to measure the reaction should meet three requirements:

1. It should keep the electric wave sent through the measuring instrument proportional to the change in the organism.

2. It should provide some means of offsetting any general drift in the subject's impedance so as to keep the recording instrument on its scale.

3. It should keep the current through the subject at very near the same value. If the reflex is a polarization phenomenon one would expect the current to affect the reaction. Evidence is presented in Chapter III to show that this is the case.

Connecting a subject directly to the galvanometer fulfills none of these conditions. If a variable counter e.m.f. is inserted, current flow can be kept at zero, and the recorder on the scale. This is the circuit most used with a string galvanometer (8, 49). In the light of the results of Jeffress (29) and the theory of Gildemeister the circuit does not appear adequate to make the galvanometer deflection proportional to the body change. Excitation occurs at any point on the skin, in nearly the same amount, decreasing the positive ions on the outside of the membranes and making the point negative to a non-excited point. If, however, two points are connected the P. D. between these two will not be the total change at either point, but the difference between the two. Some results might be expected from the method, since the differences between excitations are perhaps roughly proportional to their magnitude.

A simple circuit devised by Godefroy (24) and recommended by Landis and DeWick (33) and Wechsler (47) has the subject and source in the primary of a transformer and the galvanometer in the secondary. That is an extremely unsatisfactory arrangement. The indicator will not drift off the scale, but transformers are constructed to transmit without distortion only certain frequencies, or rates of change. The transformers ordinarily used are designed to go down only to 50 cycles per second. A transformer capable of handling changes equivalent to $\frac{1}{8}$ cycle per second would be extremely large and expensive if not impossible to construct. The peculiar and miscellaneously shaped waves obtained by

Godefroy should show that the method does not really measure the reaction.

The most common circuit used for study of the galvanic reaction is the wheatstone bridge. Probably the reason for its wide use is the possibility of "compensation" for any large change in the subject by varying the resistance in the other part of the subject's branch. But as it is ordinarily used the electrical relations become extremely complicated, and direct proportionality of deflection to resistance change is lost.

If the bridge is allowed to remain out of balance, as it was in Smith's research (42), or if the ratio is changed, proportionality is even more distorted. Radeki (37) overcame these difficulties by constantly changing R_3 to keep the galvanometer at zero, and recording the movement of the slide on the variable resistance with a revolving drum.

Several methods have been suggested for keeping the current through the subject constant. Prideaux (36) inserted a meter and variable resistance in the arm of the bridge with the subject, and kept the meter approximately at the same reading by varying the resistance. This is an excellent circuit and it keeps the current through the subject constant and at the same time corrects the non-proportionality of the bridge circuit to a large extent.

Wechsler's scheme for doing the same thing seems to be a mistake. First he found what voltage would pass a given current through a subject in a simple circuit. Then he put the subject into the bridge and applied that voltage to the whole network. This keeps the current constant as long as the ratio of the bridge resistance is not changed, but causes very bad disturbance of proportionality, since the "e" in the equation for the deflection will vary by at least 500% from one subject to another.

The Hathaway (26) apparatus recently put on the market seems to be a device with excellent possibilities. The measuring current used is a.c. A transformer is in series with the subject, and voltage from the secondary of it is led to the grid of the vacuum tube amplifier, the result being read on a milliammeter. The subject's current is controlled within certain limits. But the relatively small impedance of the transformer appears to disturb proportionality rather seriously. For example if a subject's total resistance were 10,000 ohms, the

impedance of the transformer equal to 100 ohms, and the applied e.m.f. E, then a drop of 1,000 ohms in the subjects would cause a change in the P. D. across the transformer of $\frac{(100}{(9,000} - \frac{100)}{10,000)}$ E, or .0011 E. If, however, the subject were originally 20,000 ohms, the e.m.f. used would be approximately 2E, and a change of 1,000 ohms would cause a change in the P. D. across the transformer of $\frac{(100}{(19,000} - \frac{100)}{20,000)}$ 2E or .0005 E. This fault in the circuit could be corrected rather simply, increasing its value a great deal.

3. Recording Apparatus Used in the Present Research

An attempt was made in constructing the present apparatus, to meet as well as possible all the requirements set forth in the preceding section.

The measuring instrument for photographic records was an oscillograph, the Westinghouse single element Osiso. The standard slow speed film holder for this instrument was belted to run at speeds between ⅛ inch per second, and 1½ inches per second. This holder uses ordinary 3A kodak films, and two records were taken on each by rerolling the film and shifting the zero point.

As supplied by the factory the sensitivity of the instrument was .140 amperes per inch. This was nearly doubled by replacing the moving element of the galvanometer with a more sensitive one—the sensitive vibrator ribbon of the General Electric Company. Tension on the element was somewhat reduced. This procedure also lengthened the period of the instrument, which was originally rated as $\frac{1}{5,000}$ of a second, very much shorter than necessary.

The important advantage of this instrument over the string galvanometer is its considerably smaller cost. Its disadvantage is that even with the sensitive element amplification of the galvanic response is necessary.

Measurements which were not taken photographically were read from a milliammeter.

One circuit through the subject was described in the *American Journal of Psychology* (5), and another will be in the *Journal of General Psychology* (52).

In Figure 1 the very high resistance of the vacuum tube

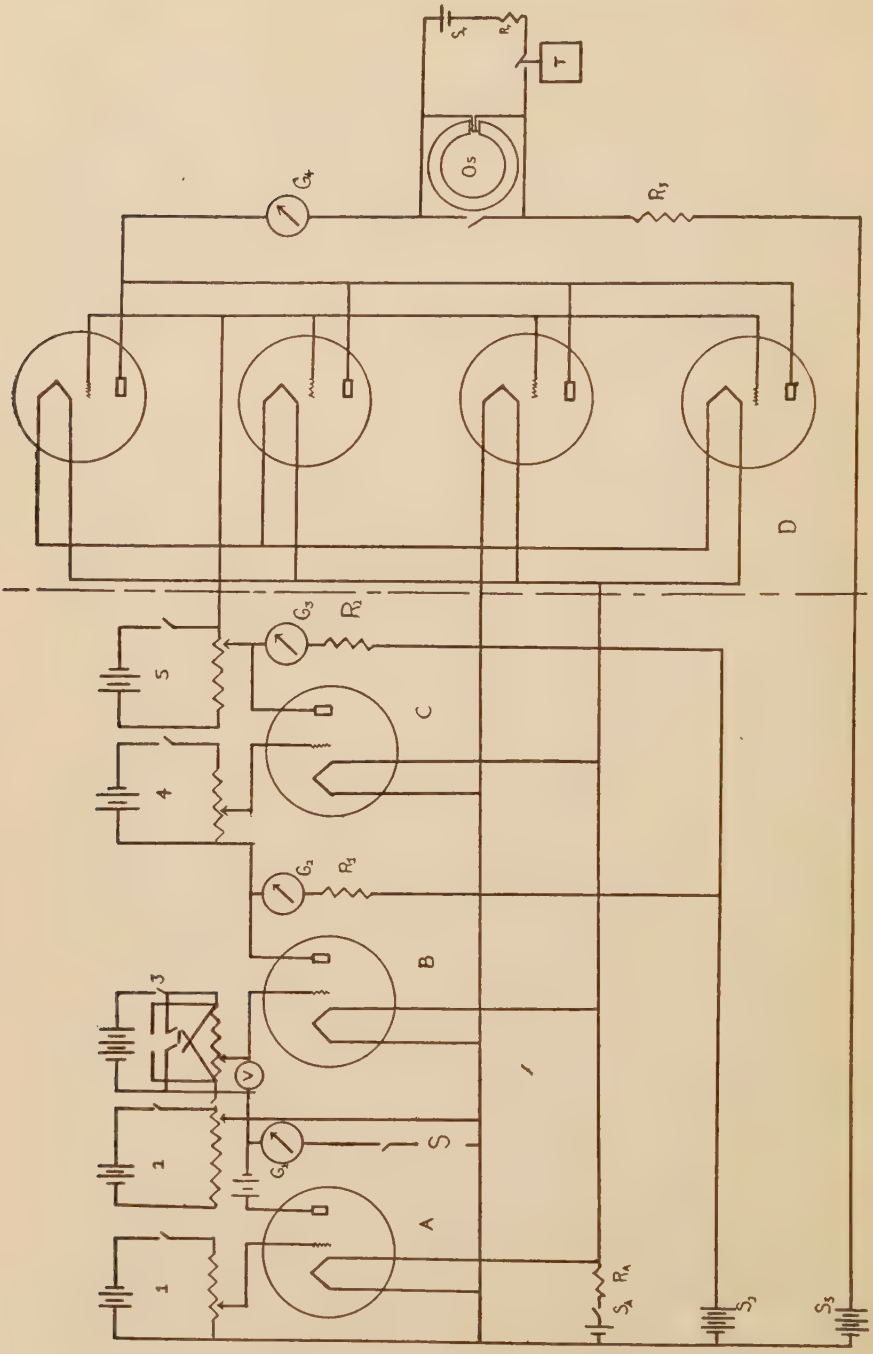


FIGURE 1.

A is in series with the subject S. This insures a constant current through the subject, which may be read on G, and regulated by changing the voltage on the grid of the tube with potentiometer 1. The battery S, is 95 volts. If the meter G, reads .3 milliamperes, the total impedance of the circuit must be $\frac{95}{.0003}$ or 316,666 ohms. Of this 20,000 may be in the subject. If the subject should drop from 20,000 to 17,000 the current would change only from .3 milliamperes to $\frac{95}{313,666}$ or .304 milliamperes, a change which can safely be neglected. If the meter reading changes much, the current can of course be set back.

By the same device proportionality is secured. The magnitude measured is the change in voltage drop across the subject. Under the conditions just described the drop across the subject at the outset would be $\frac{20,000}{316,666} \times 95$ or 1.9 volts. After the change equivalent to 3,000 ohms—for purposes of measurement it makes no difference whether the change is in e.m.f. of polarization or in pure resistance,—the voltage drop across the subject is $\frac{17,000}{313,666} \times 95$ or 1.621 volts. The ratio $\frac{1.621}{1.9}$ or .853 is substantially the same as the ratio of the two resistances $\frac{17,000}{20,000}$ or .850.

The second device used for controlling subject's current and securing proportionality was similar, but had the plate and grid of the subject's tube connected together. The tube offered a high resistance in series with the subject because of low voltage applied to the filament. This could be varied, thereby regulating subject's current to desired amount.

The voltage drop is led to the grid of the tube B. This serves two purposes, since it prevents the flow of any current at all through a branch parallel to the subject (the grid being kept negative), and also amplifies the change. But the tube of course will operate properly only for a certain range of input voltages. Therefore, a reversible and variable e.m.f. is furnished by potentiometer 3 to oppose or supplement (usually oppose) the subject's voltage drop. It is this device which serves to keep the final meter on the scale. The following

vacuum tubes are so adjusted by their potentiometers that the final meter is on the scale when, and only when, the first tube, and likewise the succeeding tubes are operating on their proper range. The other tubes, once set on their proper ranges, will stay. So the task of the operator is to reset the potentiometer 3 whenever the final meter goes off scale.

The voltmeter V is inserted to indicate how much voltage is being applied from potentiometer 3. This voltage added to or subtracted from (according to direction) the constant voltage used by the tube B gives the total voltage drop across the subject and his apparent resistance.

A sufficiently sensitive registering instrument might be inserted in the position of G 2 and act as the final instrument, but both oscillograph and milliammeter require more amplification. When readings were taken from the milliammeter the second stage of amplification consisted of two UX 201 A tubes in parallel and a 0-5 milliammeter in the plate circuit acted as indicating instrument without further amplification, the circuit ending to the left of the broken line in Figure 1.

Since the reaction wave is so slow, resistance coupling without blocking condensers must be used. In each stage the tube amplifies the voltage drop across the plate resistance of the preceding tube. To keep the full voltage of a plate circuit battery from reaching the grid of the succeeding tube the potentiometers 4 and 5 with 90 and 135 available volts, respectively, are inserted. In the last stage four power tubes are inserted in parallel to produce sufficient current to deflect the oscillograph. Their combined maximum output (undistorted) is 125 milliamperes.

Potentiometer 2 can be switched into the circuit in place of the subject, and is used for calibration and checking linearity of amplification. A resistance of 1,000 ohms and calibrated variable resistance are connected across a small source—1, 3 or 4.5 volts. As connected in the diagram an introduction of 10 ohms in the small variable will increase the grid potential on tube B by $\frac{1}{100}$ of the small source. For linear amplification these voltages should give proportional deflections on the final meter.

Three levels of sensitivity are made available by changing the tubes in the position of the second amplifier C. This requires a change in the settings of potentiometers, but can be accomplished in 30 seconds.

In certain experimental series, as will be indicated, a condenser of 2 mfd. was connected from the grid to the negative of the first amplifier, and a condenser of 1 mfd. from the grid to the negative of the second amplifier. The purpose of these condensers was to filter out stray alternating currents.

Since the second condenser is shunted across the plate resistance of ¼ megohm, the possibility of its distorting the reflex wave must be considered. Gildemeister (18) has derived the equation already mentioned which he found to give a fairly exact fit to the reflex wave. In order to compare obtained curves with this, some point of reference other than the origin of the wave must be decided upon. The maximum would not serve, since distortion would be greatest there. Distortion by the condenser would, of course, depend on the rate of change, and if the rate of change were small over a period would approach zero. This is what occurs in the tail of the wave defined by the equation. Supposing, then, that true and distorted waves nearly coincide at some point in their tails, a point 2 times as far from the origin as the maximum is, was chosen to fit theoretical curves for comparison. There was found to be little difference between theoretical and obtained maxima, the obtained averaging 0.7 per cent less in 30 cases, that is to say distortion, if present, is nearly equal at these two points. Since it may be considered negligible at the point in the tail it seems to be an unimportant factor. Complete reliance, however, need not be placed on measurements validated by this method, since all measurements taken with the filter condensers are duplicated on apparatus without, whenever there is possibility of distortion.

Since the oscillograph had but one element it was necessary to use it to indicate time as well as response. A Jaquet chronograph T, dry cell and resistance were connected directly to the oscillograph.

Although this apparatus is rather complex, some such circuit seems to be required in order to meet the needs of speed and sensitivity of galvanometer, proportionality of readings, constancy of subject current, and adjustable scale range.

The electrodes used were the customary Zn-Zn SO_4 NaCl (normal). To get approximately the same area exposed on each subject the two fingers used were wound with adhesive tape above the top of the nail. During those experiments which were recorded photographically the electrodes were kept immersed in a bath at approximately body temperature. They were made up only long enough before a sitting for them to come to temperature. Gildemeister's work indicates that there may be an effect of temperature on the reflex.

4. Stimulation Apparatus

For the present investigation it was necessary to have stimuli of the same constant intensity and constant duration at intervals subject to control. It was also necessary to get a record of the appearance and duration of these on the oscillogram of the subject's responses when they were photographed.

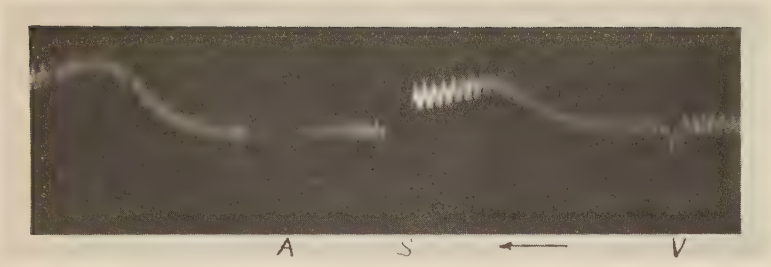
Auditory and visual stimuli seemed most convenient. The subject sat alone in a darkened and sound insulated room. Sound stimuli were presented by means of ear-phones which he wore, and the light stimulus, the spectrum of an incandescent lamp appeared on a screen before him or was the momentary glow of a neon lamp. Sound was produced by a constant voltage of 60 cycle a.c. or in some series the discharge of a condenser. For a weaker sound ear-phones of different resistance were substituted.

The duration of these spectrum and 60 cycle sound stimuli was governed by the fall of a Wundt hammer. (W) in Figure 2. By connecting the core of the holding magnet, and the metal upon which the hammer falls alternately in the circuit with the hammer itself, the circuit was closed when the hammer was in either the upward or the downward position. When this was closed the magnets of the relay R were activated and the secondary relay circuit to the spectroscope or ear-phones was closed, this being closed during the drop of the hammer. To produce a short sound the fall of the hammer could be stopped by a control half way down.

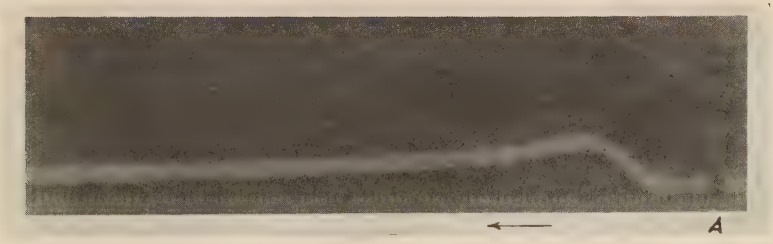
The five pole double-throw switch S made possible the change from a.c. for sound to the d.c. used for light. Power for the mechanism was derived from the 110 and 120 volt lines and reduced by 10 watt lamps.

To produce a signal of the sound on the oscillogram the transformer T is shunted across the ear-phones with the oscillograph and a resistance in its secondary. For the signal of the light the relay R_2 is shunted across the lamp with a dry cell, resistance and the oscillograph in the secondary. Plate I shows the type of record yielded by the apparatus. The very small oscillations on the line in both figures is the remaining leakage of a.c. from other circuits in the building. About half the records taken have the time line superimposed as in Plate IA. Little error was found however in running the film a third time for the time line, as in Plate IB, relying on the constancy of the driving motor.

When the neon lamp and condenser discharge were used as light and sound stimuli a 2 mfd. condenser was changed to 180 volts and discharged either through the lamp, or through the ear-phones and a resistance, according as a double-throw switch was turned. The condenser discharge produced light and sound stimuli of approximately constant intensity and duration.



A



B

PLATE *I.*

A—Auditory Stimulus.
S—Film Stopped Between Reflexes.
V—Visual Stimulus.

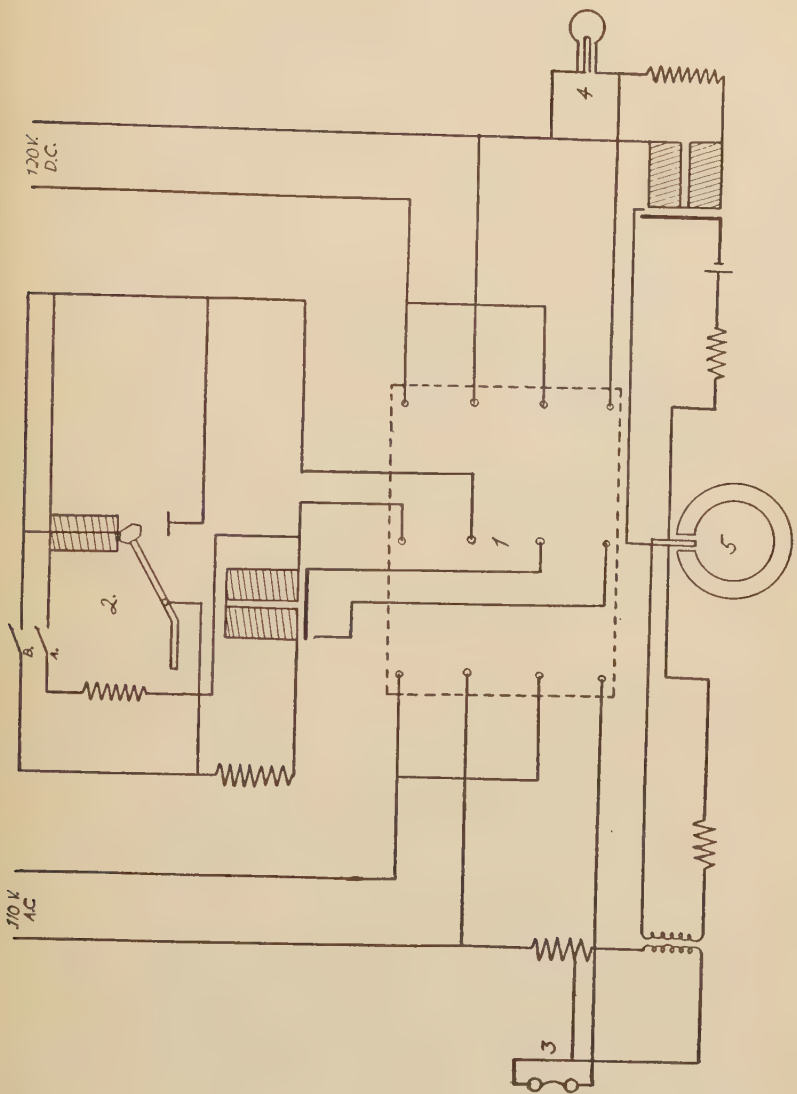


FIGURE 2.

CHAPTER III

THE RELATION BETWEEN MEASURING CURRENT AND GALVANIC REFLEX

Since there is much present dispute about the physiological nature of the reflex, a determination of its behavior under various physical conditions is important. If the physical nature of the reflex can be settled, at least certain physiological theories can be disproved and possibly the correct one decided upon.

Physically the reflex might be any one of four things. First a rather brief and regular decrease in pure resistance to an electric current. Second, it might be an electromotive force generated somewhere in the body. Third, it might be a decrease in polarization or fourth, a combination of some of the three phenomena mentioned. A crucial experiment to decide the question is the determination of the behavior of the reflex under various strengths of measuring current. If the reflex is a pure resistance change it will be the same, when expressed in ohms, no matter what the measuring current is. Deflection of an indicator if the circuit is correct will be just five times as great if measuring current is five times as strong. If on the other hand the reflex is an electric potential set up in the body the absolute size of the deflection will remain the same no matter what the measuring current. If neither of these results is the case we must fall back on the two remaining hypotheses. If the reflex were a combination of resistance and evoked potential, the relation between current and reflex should be linear, if it were depolarization it would not necessarily be so. Much curvature in the relationship would likewise seem to eliminate other possible combinations.

In conducting such an experiment measuring current rather than measuring voltage ought to be the variable considered. One may wish to conclude that the reflex is a change in polarization, and polarization as a physical phenomenon is dependent primarily on the amount of current passing. As mentioned in Section I the nature of apparent body resistance is such that doubling a voltage applied more than doubles the current passing. Aside from this physiological fact there is the dubious proportionality of readings to true changes when current is allowed to vary.

There is besides the theoretical implications of current effect, the practical question of whether current needs to be controlled in galvanic reflex investigation.

Gildemeister (13) investigated the behavior of the reflex in alternating current by passing alternating and direct current through the body simultaneously. Since he found the reflex absent in alternating current he concluded that it was a matter of depolarization, which could not take place under a.c. because that current had already depolarized the tissues. Complete absence of reflex under any a.c. cannot be maintained in the face of the reflexes so readily obtained by the Hathaway apparatus which uses a.c., and as Thouless (46) points out would not be expected on theoretical grounds since a.c. of low frequency would come a long way from producing complete depolarization. Thouless' recent experiments indicate a diminishing of the reflex with an increase of frequency of alternation. Sung Sheng and Lehman (45) conducted an experiment to determine the effect of varying applied voltages on the galvanic reflex. They found that deflections in millimeters (which in their circuit amounted to expressing the reflex in terms of volts) were greater with greater applied voltages. Although they looked for a change in the ratio of evoked volts to applied —approximately expressing the reflex in ohms—they were unable to find any stability or trend. They had but few cases, and their use of potential rather than current as a variable seems to be an error.

The present experiments were designed to determine the existence, and if possible, the amount of any effect of current on the reflex. The extreme variability of the size of the reflex makes it difficult to get comparable readings at each intensity of current. The following plan was followed in two series of experiments. After a rest period of four minutes twelve reflexes were evoked at one minute intervals, current values .1, .3 and .5 milliamperes being rotated so as to give four readings at each intensity. A standard sound stimulus was used, in the first experiment the brief duration of 60 d.v. tone, and in the second the discharge of a condenser through phones. One sitting of this sort of procedure would give an advantage to whatever value of current happened to come first because of the rapid fatigue of the reflex—it frequently disappeared before the end of a sitting. Therefore, each subject was given three sittings, one with the order .1, .3, .5, one with .3, .5, .1,

and one with .5, .1, .3. In the first experiment all subjects were subjected to .1, .3, .5 order first, in the second equal numbers were started with the other two orders. The area of the fingers immersed in the electrode from day to day was kept as nearly the same as possible by having a bandage of waterproof tape at the base of the nail of the reacting fingers. With these precautions there are still the variables of daily changes in the subject's reactivity and of individual differences in reactivity. A seemingly successful attempt is made to allow for these in the calculation of the results.

Three subjects were used in the first experiment, but each was put through the series twice, making six sittings each. Six different subjects were used in the second, each being given only the three sittings. An attempt of very doubtful success was made to control the temperature of the electrodes during the first sitting by keeping them immersed in a thermostat. The reflexes in the first series of experiments were photographed, and in the second read from the milliammeter. Readings were taken of the subject's total resistance before each reflex. Filter condensers were present in the first experiment but not in the second.

The first step in the treatment of results was to multiply each reading obtained from film or meter by the calibration constant of the amplifier, determined as before described, to convert the readings to volts of input. Expressed in volts, figures were carried to four places when obtained with the amplifier at the higher sensitivities, and three when at the lowest.

Next the readings were expressed as resistance by dividing the obtained voltage by the appropriate current value. The subject's total resistance before each stimulation was computed in similar fashion from the readings of the voltmeter. The average value of reflexes at each current at each sitting was then computed for each subject, likewise the average total resistance at each current intensity.

To allow for daily and individual differences in reactivity the average of each subject's reactions, irrespective of current, was computed for each day. These values seem to represent individual and daily reactivity as nearly as it is possible to do so. One set of values was secured by expressing the average reactions and total resistances to each current each day as a percent of the average.

(The use of percents of the average is justified since $\frac{\text{Av.}}{\sigma}$ is about the same for all distributions concerned [Kelley, 32]. When this is true, and the true zero known, percents seem superior to standard scores since they involve only the error of the average, while standard scores involve both it and the error of the S.D.)

Then, in order to make possible a comparison of the absolute change in reflex with that in resistance, the percents were converted back into physical units by multiplying each by the general average reaction and resistance. This has the effect of weighting each individual's reactions and resistance for his peculiarities of reactivity or resistance.

All the reactions of a given subject to each current, (1) computed as voltage, and (2) computed as resistance, after they had been treated in the above fashion to correct for daily variation and individual differences were then averaged, thus equalizing position in series. Total resistances were accorded the same treatment. This calculation yields the following sets of figures.

1. Reflexes by currents, expressed in volts and treated as percentages. Tables I and II.

2. Reflexes by currents, expressed in ohms and treated as percentages. Tables III and IV.

3. Reflexes by currents, expressed as ohms and weighted for individual differences. Tables V and VI.

4. Total resistances, expressed as ohms and weighted for individual differences. Tables VII and VIII.

TABLE I. REFLEX (IN VOLTS) AS PER CENT.
First Experiment.

	.1 Ma		*.3 Ma*		*.5 Ma*
Subject 1	49		102		146
Subject 2	66		112		130
Subject 3	30		81		121
Subject 4	49		87		150
Subject 5	43		102		162
Subject 6	62		116		134
Average	50		100		147.3
	11.8		12.5		13.4
$P.E._{Av.}$	3.2		3.4		3.7
Diff.		(Column 2-1)	50	(Column 3-2)	42.3
$P.E._{Diff.}$			4.7		5.2
$\frac{D.}{P.E.}$			10.6		8.1

TABLE II. REFLEX (IN VOLTS) AS PER CENT.
Second Experiment.

	.1 Ma		.3 Ma		.5 Ma
Subject 1	4.4		119.7		137.7
Subject 2	42.7		104.3		190
Subject 3	61		103.3		138.7
Subject 4	55.3		115.3		131.
Subject 5	82.		75.7		142.6
Subject 6	57.3		96.0		173.
Average	57.5		96.0		52.2
	10.6		27.2		23.5
$P.E._{Av.}$	3.		6.1		5.9
Diff.		(Column 2-1)	38.5	(Column 3-2)	56.2
$P.E._{Diff.}$			6.8		8.5
$\frac{D.}{P.E.}$			5.7		6.7

TABLE III. REFLEX (IN OHMS) AS PER CENT.
First Experiment.

	.1 Ma		.3 Ma		.5 Ma
Subject 1	118.3		88.4		90.5
Subject 2	120.1		100.4		85.7
Subject 3	132.7		86.3		106.9
Subject 4	114.1		118.6		72.7
Subject 5	105.6		86.1		55.7
Subject 6	123.8		83.6		91.9
Average	119.1		93.9		88.8
	8.3		12.5		10.
$P.E._{Av.}$	2.3		3.44		2.75
Diff.		(Column 1-2)	25.2	(Column 2-3)	5.1
$P.E._{Diff.}$			4.1		4.4
$\frac{D.}{P.E.}$			6.1		1.2

TABLE IV. REFLEX (IN OHMS) AS PER CENT.
Second Experiment.

	.1 Ma		.3 Ma		.5 Ma
Subject 1	113.3		95.3		92.3
Subject 2	112.7		90.7		99
Subject 3	142		89.7		84
Subject 4	126.7		104.7		77.7
Subject 5	162		68.7		70.6
Subject 6	146.3		67.		92.3
Average	133.9		85.7		85.
	15.9		31.2		13.7
$P.E._{Av.}$	4.4		8.55		3.6
Diff.		(Column 1-2)	58.2	(Column 2-3)	.7
$P.E._{Diff.}$			9.6		9.3
$\frac{D.}{P.E.}$			6.6		.08

TABLE V. REFLEX IN OHMS.
First Experiment

	.1 Ma	.3 Ma	.5 Ma
Subject 1	252	189	194
Subject 2	258	216	184
Subject 3	284	185	228
Subject 4	246	255	156
Subject 5	226	185	184
Subject 6	266	179	197
Average	256	205	191

TABLE VI. REFLEX IN OHMS.
Second Experiment.

	.1 Ma	.3 Ma	.5 Ma
Subject 1	694	584	564
Subject 2	690	555	605
Subject 3	860	549	514
Subject 4	770	640	475
Subject 5	992	421	432
Subject 6	896	410	567
Average	818	525	520

TABLE VII. TOTAL RESISTANCE—HUNDREDS OF OHMS.
First Experiment

	.1 Ma	.3 Ma	.5 Ma
Subject 1	193.	177	167
Subject 2	194.	176	173
Subject 3	193.	171	161
Subject 4	218	172	160
Subject 5	183	179	182
Subject 6	203	166	166
Average	198	174	168

TABLE VIII. TOTAL RESISTANCE IN HUNDREDS OF OHMS.
Second Experiment.

	.1 Ma	.3 Ma	.5 Ma
Subject 1	260	232	214
Subject 2	268	228	210
Subject 3	254	237	215
Subject 4	271	230	206
Subject 5	270	225	211
Subject 6	262	218	225
Average	264	226	213

Figures 3 and 4 are constructed from the data of Tables I and III and II and IV.

Figures 5, 6, 7, and 8 are constructed from Tables V, VI, VII, and VIII.

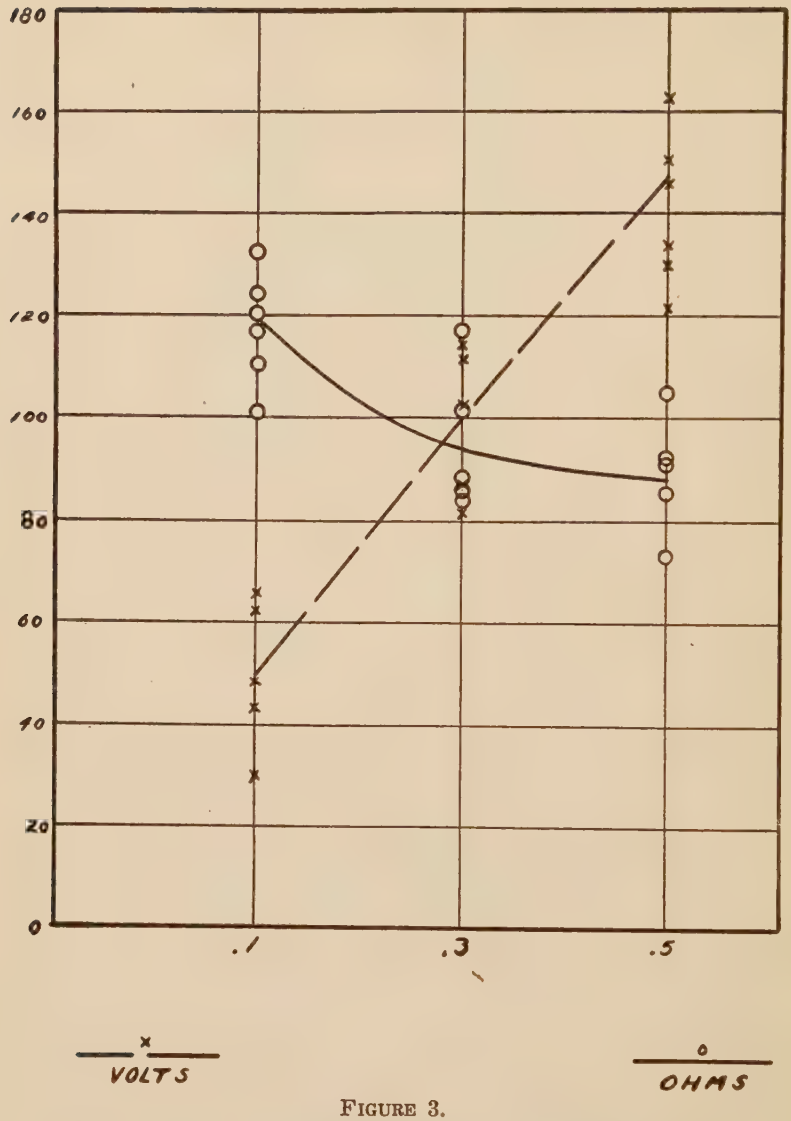


FIGURE 3.

Reflex in Volts and Ohms as Per Cents at Various Currents (Milliamperes).

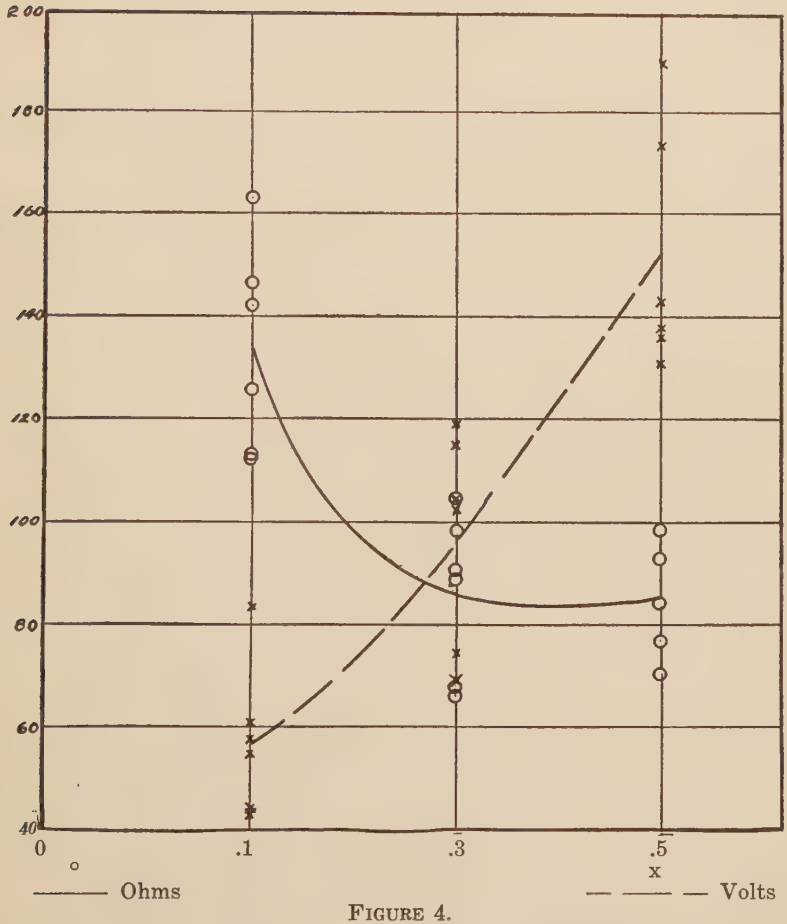


FIGURE 4.

Reflex in Volts and Ohms as Per Cents, Second Experiment.

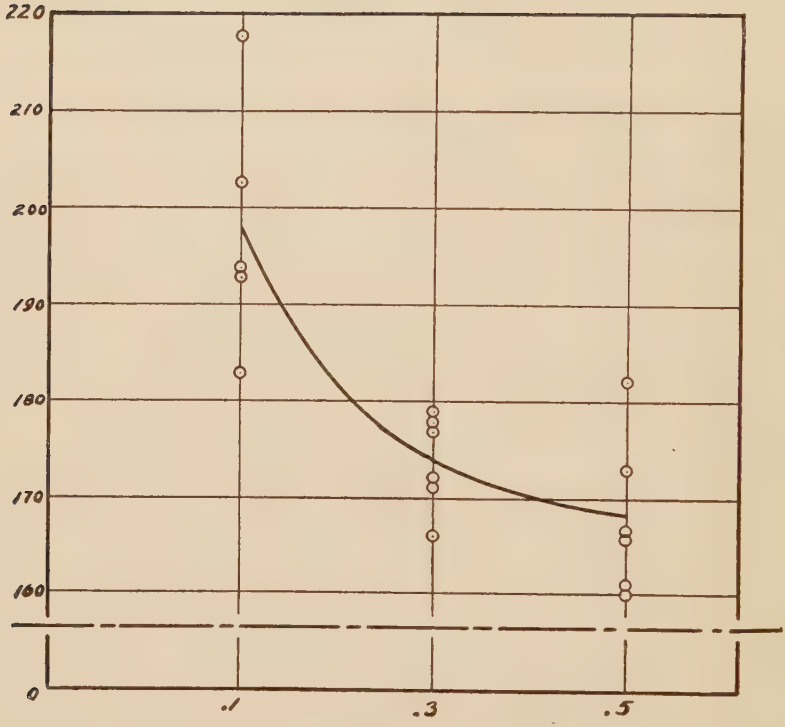


FIGURE 5.
Total Resistance in Hundreds of Ohms, First Experiment.

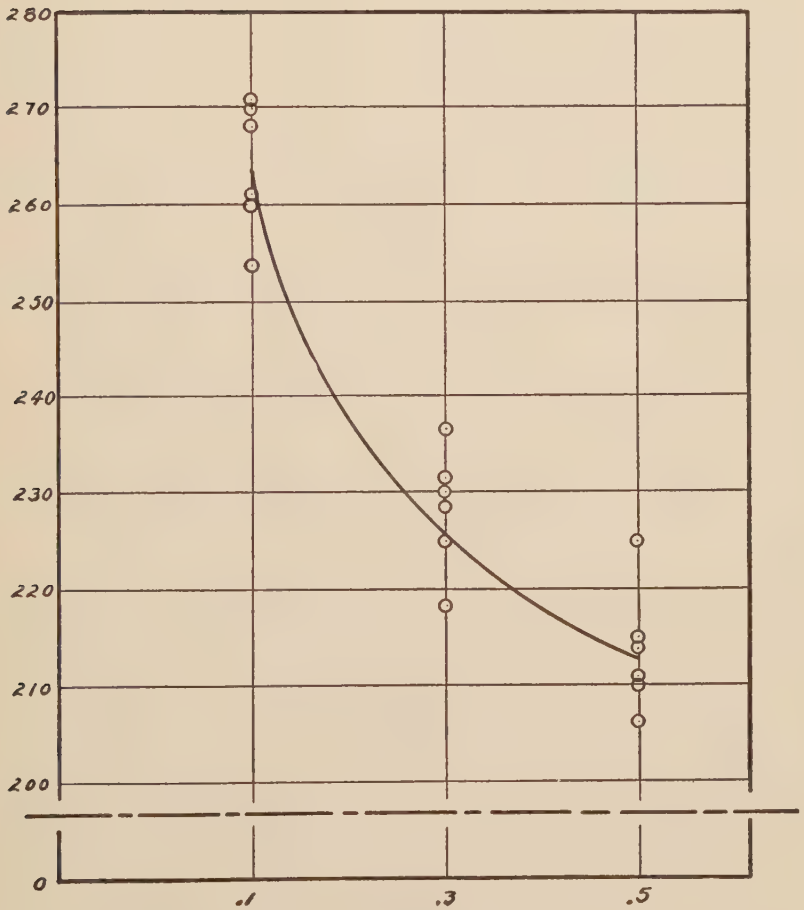


FIGURE 6.
Total Resistance in Hundreds of Ohms, Second Experiment.

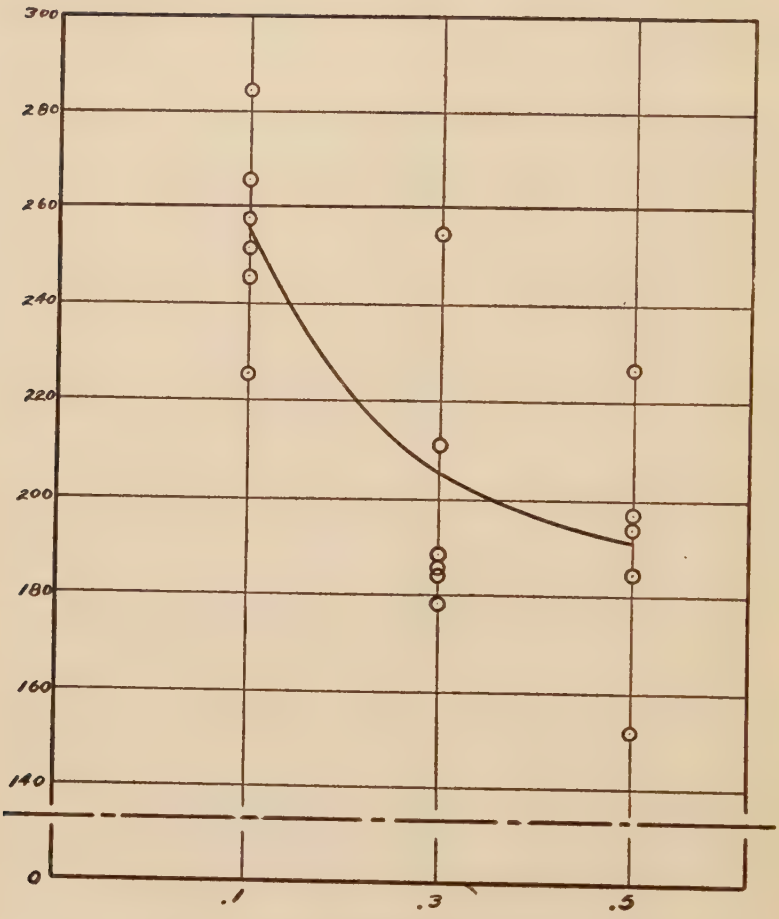


FIGURE 7.
Reflex in Ohms at Various Currents (milliamperes), First Experiment

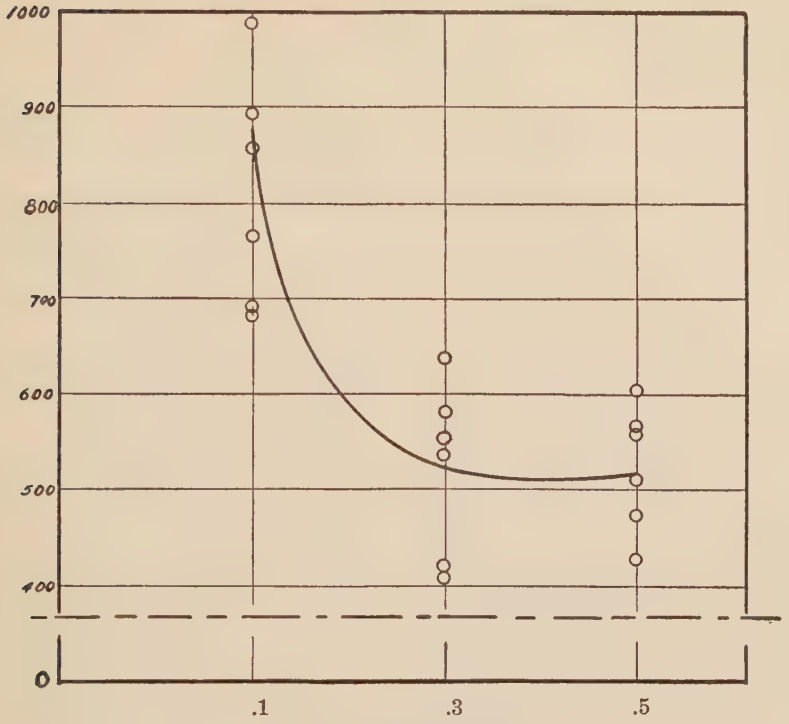


FIGURE 8.
Reflex in Ohms, Second Experiment.

In Figures 3 and 4 the dotted line representing the reflex in volts as a function of current shows the same results Sung Sheng and Lehman found, except that here the ordinate is current through the subject rather than voltage applied. Owing to the large number of readings the present curves are more reliable. The solid line represents the reflex expressed in ohms.

Returning to the alternatives described at the beginning of the section it must be concluded that the reflex behaves like neither a simple evoked voltage nor like a simple resistance change. If the first were the case the dotted line would be straight and horizontal, if the second, the solid line would be. The reflex is more like a resistance than a voltage change. Considering the last two alternatives, one must conclude from the curvature of the solid line that the reflex behaves more as though dependent on polarization than like a combination of pure resistance change and evoked potential. It would be im-

possible to deny on these grounds that there is a substratum of the reflex which is pure resistance or pure voltage change unless the curve were carried to zero, and that would be impossible on account of the discomfort to the subjects. There is much to be said, however, on other grounds for supposing that the reflex is a single sort of occurrence. The equation describing the change fits the wave so closely in practically all cases that one can hardly think of it as anything but a single process, or a number of processes so closely related as to be practically one.

From the nature of the current-reflex relation there must be drawn the practical conclusion that during any sort of exact experimental work on the reflex the measuring current should be controlled for physiological as well as physical reasons. This is best done by the technique described in the section on apparatus.

To arrive at the nature of the current-reflex effect it is desirable to compare it with the current-resistance relation.

The falling of resistance with increased current, as previously mentioned, is very well known. Gildemeister (21) has published a curve which, connected to similar coördinates, bears a close resemblance to the one found here. By experiment upon a fresh corpse Gildemeister and Kaufhold (15) found resistance to 110 and 220 volts to be only 200-300 ohms. In view of these facts it can hardly be doubted that polarization plays a major part in the impedance of the body, and that pure resistance is almost negligible.

The similarity of the reflex-current curve suggests that similar mechanisms may produce both. According to the membrane depolorization theory of the reflex the disposition of ions in a resting body cell is similar to the schematic diagram in Figure 9a.

The membranes concerned, being semi-permeable, allow positive ions to pass to the outside. Increase in permeability of the membranes to allow negative ions to pass would cause the excited cell to be negative to an unexcited one, constituting the action potential or so-called phenomenon of Tarchanoff.

If a current from an external source is passed, the situation becomes somewhat as represented in Figure 9b. According to Lullies' work (35) the membranes behave like condensers, shunted across a resistance. Since the e.m.f. of polarization at B is in the same direction as the applied

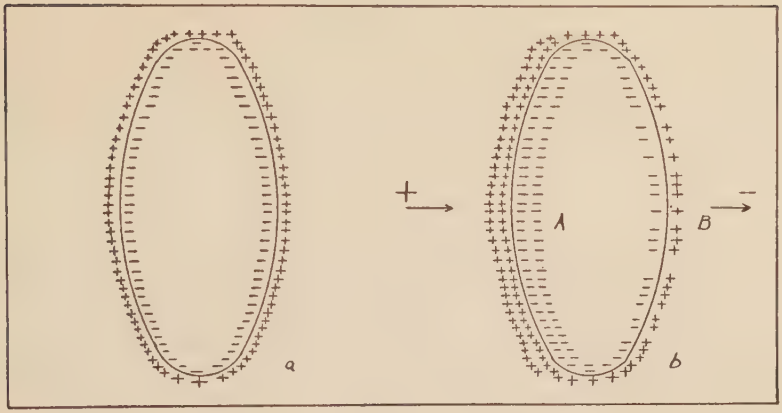


FIGURE 9.

e.m.f. and at A in the opposite, the current flowing becomes $I = \frac{E + e_B - e_A}{W + w}$ where E is the applied potential, W the resistance of the subject's tube and w a constant depending on area and the chemical constitution. With a decrease of W, I would increase making a greater double layer at A and less at B. That this agglomeration of ions toward the anode actually takes place is borne out by the staining methods of Bethe.

It is clear that any depolarization due to increased permeability of the membrane would appear as a lessening of resistance if it occurred at A, and as an increase if it occurred at B. All galvanic reflexes measured by the resistance method are, with the exception of the negative fore-phenomenon, which may be explained on these grounds, decreases in apparent resistance. Evidently, then, the dominant contribution to the reflex is from the membranes toward the anode. This seems reasonable since there is a greater e.m.f. of polarization at those points. The greater the current, the less part in the reflex would be contributed by the anode-ward membrane.

With these considerations in mind an explanation of the effect of current on reflex seems to offer itself. With higher current intensities the anode membranes become more polarized and consequently when depolarized in a reflex show a greater reflex in terms of potential as the voltage curves in Figures 3 and 4 require. Meanwhile the potential change in the opposite direction of the anode gradually becomes smaller, thereby increasing the size of the reflex.

But if current is increased by a given factor, say becoming five times as great, it would not be expected that polarization would increase by exactly the same factor, since that is also defined by the number of ions available, which with an increasing current would follow the law of diminishing returns. Thus the apparent resistance to higher currents would be less on account of their being less than proportional counter e.m.f. On the same account less than the proportional reflex would be possible, and the reflex expressed as resistance change would decrease with measuring current.

Insofar as this explanation is correct the results lend weight to the membrane depolarization theory of the reflex and throw some further light on its mechanism.

CHAPTER IV

LATENT AND RISING PERIODS OF THE REACTION WAVE

1. Latent Period

Comparatively little attention has been paid to other characteristics of the reaction than its amplitude. Gildemeister (20) compared the latent periods of the reflex with and without measuring current and found them practically the same. He also (19) studied the effect of local temperature on the latent and rising periods.

The latent period may be defined as the interval between the onset of the stimulus and the moment when apparent resistance begins to decrease. Some difficulty in its measurement arises because of the occasional presence of the negative fore-phenomenon, a slight increase in resistance preceding the main reaction. In accordance with the theory of the reflex outlined by the data of the preceding section, this may be regarded as due to the cathode membranes getting into action occasionally before the anode. Measurements in the present investigation were taken to the beginning of the decrease in resistance even though it occurred in the negative fore-phenomenon, since it seems likely that the fore-phenomenon is blotted out by the major wave rather than by its own decay. The rising period of the wave was measured from this point to the peak of the wave.

Gildemeister undertook to investigate the effect of temperature on these periods (also on the amplitude) because of the weight that a temperature effect would lend to the membrane depolarization theory of the reaction. He found both periods, the rising period more definitely, shorter with higher skin temperatures. This being rather important it would be well for the experiment to be repeated, since he used but 35 reactions as a basis for his conclusions.

The latent period is affected by the measuring current only slightly or not at all. Table IX summarizes the measurements on latent period taken from the first experiment described in Chapter III.

Consequently latent periods taken with different measuring currents may be compared without great error.

TABLE IX. LATENT PERIOD (IN SECONDS) AND CURRENT.

	.1 Ma	*.3 Ma*	*.5 Ma*
Subject 1	1.938 ± .024	1.905 ± .023	1.885 ± .024
Subject 2	1.889 ± .028	1.905 ± .028	1.964 ± .026
Subject 3	1.977 ± .034	1.950 ± .037	1.945 ± .030
Total	1.926 ± .011	1.924 ± .016	1.931 ± .015

Table X presents the average latent periods to spectrum and sound stimuli for twelve subjects. The procedure for the first eight was to give stimuli in the order 3 light, 3 sound, 3 light, 3 sound, 3 light. Some subjects were given this procedure at a number of sittings. With the last four subjects stimuli were given in chance order. One minute intervals were allowed between all stimuli. This table shows some evidence of individual differences, but in all cases the latent time was less in reactions to sound than it was in reactions to the spectrum.

TABLE X. LATENCY BY STIMULUS.
(In Seconds.)

Subject	*Light*	*Sound*	*Diff.*	$\frac{D}{P.E.}$
1	2.02 ± .027	1.63 ± .016	.39 ± .031	12.5
2	1.94 ± .018	1.72 ± .044	.22 ± .047	4.7
3	1.87 ± .045	1.55 (N = 2)	.32	—
4	2.29 ± .075	1.92 ± .032	.37 ± .081	4.6
5	1.90 ± .041	1.79 ± .038	.11 ± .055	2.
6	2.07 ± .064	1.55 ± .125	.52 ± .140	3.7
7	1.85 (N = 2)	1.55 (N = 3)	.30	—
8	2.13 ± .092	1.72 (N = 3)	.41	—
9	2.20 ± .057	1.67 ± .051	.53 ± .076	7.
10	2.53 ± .077	2.20 ± .074	.33 ± .107	3.1
11	2.03 ± .063	1.67 ± .011	.36 ± .064	5.6
12	2.31 ± .104	2.02 ± .051	.29 ± .116	2.5

For comparison a similar table (Table XI) of amplitudes of the same reactions is presented. The correspondence between differences in the two tables is quite noticeable.

Two subjects in the first experiment described in Chapter III by the end of their first three sittings became so adapted to the sound stimulus used that they almost ceased to respond to it. Their second series of three sittings were taken with a sound stimulus considerably stronger. The latent times and size of reactions are compared in Tables XII and XIII, subjects 1 and 2. One subject responded to the weaker sound all through the experiment on current effect, and then acted as

TABLE XI. SIZE BY STIMULI.
(In Ohms.)

Subject	Light	Sound	Diff.	$\frac{D}{P.E.}$
1	138 ± 13	734 ± 24	596 ± 27	22.0
2	356 ± 40	650 ± 42	244 ± 58	5.1
3	125 ± 17	134 (N = 2)	9	—
4	323 ± 83	1110 ± 7	787 ± 83	9.5
5	140 ± 31	620 ± 170	480 ± 173	2.8
6	597 ± 81	972 ± 113	375 ± 139	2.7
7	5 ± 1.2	944 ± 62	939 ± 63	14.9
8	190 ± 30	740 ± 85	550 ± 90	4.9
9	337 ± 46	650 ± 39	313 ± 60	5.2
10	38 ± 12	309 ± 59	271 ± 60	4.5
11	241 ± 39	391 ± 68	150 ± 78	1.9
12	16 ± 5	340 ± 40	324 ± 40	8.1

TABLE XII. LATENT PERIOD BY STIMULI AND SUBJECT.
(In Seconds.)

Subject	Weak	Strong	Diff.	$\frac{D}{P.E.}$
1	1.95 ± .010	1.60 ± .016	.35 ± .019	18.5
2	1.93 ± .017	1.94 ± .028	—.01 ± .033	— .3
3	1.95 ± .022	1.94 ± .032	.01 ± .039	.3
4	2.55 ± .083	2.31 ± .064	.24 ± .109	2.3

TABLE XIII. SIZE OF REFLEXES TO WEAK AND STRONG STIMULI.
(In Ohms.)

Subject	Weak	Strong	Diff.	$\frac{D}{P.E.}$
1	41 ± 3	33 ± 4	8 ± 5	.6
2	309 ± 50	734 ± 24	425 ± 55	7.5
3	113 ± 16	158 ± 25	45 ± 30	1.5
4	56 ± 12	249 ± 39	193 ± 41	4.7

subject in the comparison of light and sound reactions just described in which the stronger sound was always used. The averages of responses to sound in these two series are compared in Tables XII and XIII, subject 3. Subject 4 in these tables underwent an experiment on seven different days in which stimuli were given as follows: 3 weaker, 3 stronger, 3 weaker, 3 stronger, 3 weaker.

These two tables likewise show a rather close correspondence between size of reaction and latency. These and the preceding two tables suggest the possibility of a correlation between latent period and amplitude when the stimulus is un-

changed. Table 14 presents a number of such correlations, some within the reaction of the individual and some within a group. The first three correlations are taken from the reflexes of the three subjects in the first experiment on current

TABLE XIV. CORRELATION BETWEEN LATENT PERIOD AND SIZE OF REFLEXES.

	Stimulus	*N*	ρ	$\frac{D}{P.E.}$
Subject 1	Weak sound	27	—.399	.110
Subject 4	Light	27	—.064	.128
Subject 2	Strong	29	—.271	.116
Subject 2	Weak sound	27	—.113	.114
Subject 3	Weak sound	84	—.200	.071
Group A	Short sound	22	—.118	.142
Group B	Light	18	—.295	.144

effect (only those reactions to one intensity of sound being considered). The fourth correlation is taken from the experiment just described in which a single subject submitted to a series of sittings in which groups of light and sound stimuli were alternated. Only reactions to the spectrum were considered. As will be described in a later section this same procedure was given to a group of subjects with one sitting each. The correlation for Group A considers data from the first reaction of each of these subjects. The correlation for Group B considers data from a similar group in which a sound of brief duration was used in place of the spectrum. Taking all correlations together one may conclude that there is a small negative correlation between latent period and amplitude of reaction when the stimulus is constant.

These correlations depend on measurements made with the filter condensers in the apparatus. These would not, of course, have any effect on latent or rising periods. Aside from the argument against great distortion of amplitude previously considered the following facts tend to show that these correlations are not introduced by the condensers: (1) Gildemeister (19) found that both latent and rising periods tend to become longer with rising temperature. (2) A comparison of latent and rising periods to be made in the next section indicates that their correlation is zero or slightly positive. Such a relation would tend to reduce the negative correlation between latency and amplitude, since a wave of shorter rise would be more flattened by the condensers than a wave of longer rise.

The influence of duration of the stimuli upon latent period was investigated by comparing latent periods for long and short sound stimuli. (See chapter on methods of measure-

ment.) A group of eight subjects was given stimuli in the following order: 3 short, 3 long, 3 short, 3 long, 3 short. It will be noticed that any effect of time is at least partly controlled by having a group of short stimuli at both beginning and end of the series. Table XV presents the differences found in seven subjects. Table XVI gives the differences in amplitude of these reactions. There may be some indication of a general difference in latent period, but the results are not conclusive. Evidently, judging from the table of amplitudes, the stimuli were not sufficiently different to decide the question.

TABLE XV. LATENT PERIOD OF REFLEXES TO LONG AND SHORT STIMULI. (In Seconds.)

Subject	*Short*	*Long*	*Diff.*	$\frac{D}{P.E.}$
1	2.21 (N = 3)	2.50 (N = 4)	—.29	—
2	1.81 ± .060	1.64 ± .061	.17 ± .085	2
3	2.11 ± .039	1.83 ± .042	.28 ± .057	4.9
4	2.01 ± .041	1.96 ± .051	.05 ± .065	.8
5	2.19 ± .050	1.92 (N = 3)	.27	—
6	1.67 ± .032	1.63 ± .022	.04 ± .034	1.2
7	1.85 ± .043	1.70 (N = 2)	.15	—
Average	1.94	1.86		

TABLE XVI. SIZE OF REFLEXES TO SHORT AND LONG STIMULI. (In Ohms.)

Subject	*Short*	*Long*	*Diff.*	$\frac{D}{P.E.}$
1	76 ± 18	67 ± 25	— 9 ± 31	— .3
2	21 ± 5.7	43 ± 6.9	22 ± 89	2.5
3	386 ± 38	476 ± 38	90 ± 54	1.7
4	307 ± 18	380 ± 40	73 ± 43	1.7
5	257 ± 71	225 (N = 2)	— 32	
6	448 ± 43	332 ± 7	—116 ± 44	—2.7
7	269 ± 27	280 (N = 2)	11	

One subject was given the procedure of alternate groups of spectrum and sound stimuli twice a day for six days. The first repetition of the procedure each day has already been considered in comparing latency to spectral and sound stimuli, but the last has not. Comparing the data of the first series each day indicates that the latent period tends to become longer with the repetition of a stimulus. The average latent time of the first repetition is 1.894 ± .014 and for the second 2.030 ± .009. The size of the reactions was, of course, defi-

nitely less in the second repetition, due to the well known "fatigue" effect.

The differences in latent times following the various stimuli correspond in direction to the differences commonly found in simple reaction time. That they are not, however, due to such differences is evident from their magnitude which is roughly ten times that of reaction time differences.

In terms of its own variability the latent period is about as much affected by the nature of the stimuli as is the amplitude of reaction. In terms of percents the differences in latent time would be smaller, since the latent time is the less variable of the two magnitudes.

These observations seem to point to a correspondence between length of latent time and amplitude of reaction. This correspondence is quite marked when reaction to different stimuli are concerned, and as might be expected from the much reduced range, less pronounced when the stimulus is the same. It would be somewhat odd to say that the latent period is affected by the amplitude of the response which succeeds it, and it would also be hard to see how the amplitude could be regulated by the latent period. It is possible that the common root lies in the frequency of nervous condition. It may be that a single fiber actually conducts faster under stronger stimulation, or it may be that various fibers with successively higher thresholds are concerned. In the first case a faster conducting fiber would be expected to recover sooner from its refractory period and conduct again, thus discharging at a higher frequency into the effector. A slow acting effector like the sweat glands might then summate these discharges and produce a greater reaction. There seems to be little direct physiological justification for such a theory, however. Another possibility is that the reacting organ requires a certain amount of energy before showing any sign of change. This amount would be supplied sooner if the neural discharge was greater.

From the data obtained it is not possible to decide whether the differences in latent time and also in amplitude in the reactions to sound and light are conditioned upon the quality or the specific intensity of the stimuli given. It is evident that somewhere in this course through the organism impulses varying originally in at least two dimensions, "quality" and "intensity," become impulses varying in only one which is tentatively called frequency. The question then becomes whether

spectra as a class give rise to impulses of less frequency than 60 d.v. sounds as a class. Presumably the classes overlap, and one might find that a given spectrum was more effective than a given sound.

On the basis of his data on the effect of temperature Gildemeister (20) attempted an analysis of the latent period into its components. Since local temperature seemed to affect the latent time he attributed 0.4 seconds of the average latent time to the effector. Subtracting this and .15 seconds for efferent conduction from a total of 1.55 seconds left 1.0 second which he rather vaguely called "central" action time. The recent work of Gasser and Erlanger (50) indicates that more time than had been supposed may be attributed to the efferent conduction. They report the existence of three groups of waves, differing in velocity and threshold. The C group of waves found "chiefly in sympathetic fibers" have the highest threshold and velocity as low as ½ to 3 meters per second. Should these slow waves be the ones concerned in the galvanic reactions, conduction over the sympathetic nerves might account for the major portion of its latent period. If the frequency explanation of differences in latent period already given should be correct it would require a fairly long conduction period, one capable of varying at least 0.3 of a second.

2. Rising Period

A treatment similar to the one just followed was accorded the rising period of the reaction, data being presented in Tables XVII, XVIII and XIX. Insofar as measures are available these are taken from the same reactions as Tables X-XVI.

Differences in Table XVII are of the same general order as those in Table IX although in the opposite direction. They are in the same direction as those in Table X. Differences are large enough to indicate that the sound stimulus produced a longer reaction than did the spectral stimulus of equal duration.

Rank order correlations between the latent and rising periods in these two tables were computed. For the two periods for the reactions to the spectrum $\rho = .04$, for the reactions to sound $\rho = .25$.

Table XVIII indicates a greater correlation between amplitude of reaction and rising time than was found between

amplitude and latent time with constant stimulus. In this case, of course, the correlation is positive.

TABLE XVII. RISING PERIOD BY STIMULI.
(In Seconds.)

Subject	*Light*	*Sound*	*Diff.*	$\frac{D}{P.E.}$
A	2.06 ± .13	2.74 ± .47	.68 ± .48	1.4
1	1.40 ± .06	2.00 ± .07	.60 ± .09	6.5
2	1.65 ± .11	2.20 ± .08	.55 ± .14	4.0
3	1.70 (N = 3)	2.20 (N = 2)	.50	—
5	1.35 ± .15	1.90 ± .21	.55 ± .27	1.9
6	2.30 ± .27	1.50 (N = 2)	—.8	—
7	1.3 (N = 1)	2.40 (N = 2)	1.1	—
8	1.28 ± .04	1.50 ± .08	.22 ± .09	2.5
9	1.48 ± .06	1.78 ± .10	.30 ± .12	2.6
10	1.68 ± .16	2.28 ± .10	.60 ± .19	3.2
11	1.49 ± .10	1.90 ± .16	.41 ± .19	2.2
12	1.25 ± .15	2.20 ± .10	.95 ± .18	5.3

TABLE XVIII. CORRELATIONS OF HEIGHT AND RISING PERIOD OF REFLEXES.

Subject	*Stimulus*	ρ	*N*
1	Light	.58	16
1	Strong sound	.47	23
1	Weak sound	.21	72
2	Light	.59	21
2	Strong sound	.61	16
3	Weak sound	.65	26
3	Strong sound	.32	17
4	Strong sound	.47	27
Group	Short sound	.35	18

TABLE XIX. RISE OF REFLEXES TO LONG AND SHORT STIMULI.

Subject	*Short*	*Long*	*Diff.*	$\frac{D}{P.E.}$
1	2.8	2.4	—.4	—
2	1.73	1.6 ± .13	—.13	—
3	1.69 ± .02	1.63 ± .04	—.06 ± .05	—1.2
4	1.52 ± .09	1.63 ± .05	.11 ± .10	1.1
5	1.96 ± .08	2.1 (N = 2)	.14	—
6	1.61 ± .04	1.14 ± .02	—.47 ± .05	—9.4
7	1.5 (N = 3)	1.6 (N = 2)	.10	—

These correlations would be too high insofar as the filter condensers in the apparatus distort the wave. A slow reaction would come nearer reaching its true maximum. Although this seems not to have been of great importance too much reliance cannot be placed on the figures.

Table XIX shows no evidence of a difference in rising time between reactions to stimuli of different duration. It is still

possible, however, that such a difference could be found if the difference between stimuli were made greater.

The difference between the rising time of the reactions to the sound and the light tends to show that amplitude and rise are mutually dependent, and the correlations between rise and amplitude with the stimulus constant supports such an hypothesis.

The fact that reactions to stronger stimuli of the same duration continue to rise longer indicates the presence of inertia somewhere in the system. Either a center once excited continues to discharge or an effector organ is merely set off by nerve impulses and continues to respond for some time thereafter. At present the latter seems the more tenable hypothesis. No mechanism of the brain or nervous system is known whose excitation and discharge last nearly so long as a second after stimulation has ceased. The fact that Gildermeister was able to vary the rising period by changing local temperature indicates that the effector organ plays at least a very important part in the rising period.

It is possible that the discharge of a nerve impulse into a cell disturbs the equilibrium of the ions and that these are slow enough in moving through the membrane to account for the lag in return to equilibrium, or perhaps the slowness is in the changing permeability of the membrane.

The possible relation between amplitude and rising period however, Gildermeister overlooked. Such a relation being present it is impossible to apply his table of corrections previously mentioned.

CHAPTER V

FACILITATION

During the course of an experiment it was noticed that a subject usually reactive failed to respond in any great degree to the spectrum on its first presentations but exhibited a very sharp drop in resistance when the sound stimuli were given, and thereafter reacted to the spectrum in his usual manner.

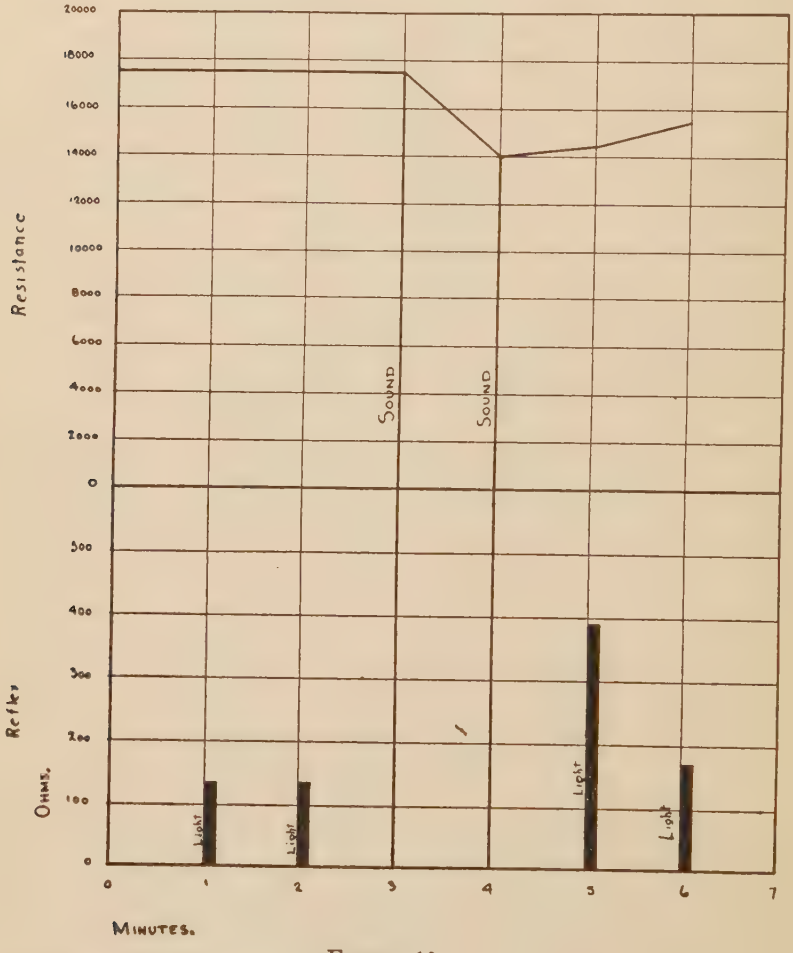


FIGURE 10.

Course of Reflex and Resistance under Varying Intensities of Stimulation.

In further observations it was found that such behavior, represented graphically in Figure 10, was not uncommon. All investigators of the reflex have observed its rapid fatigue or adaptation. A dozen stimulations at intervals of a minute are ordinarily enough to make the reflex practically disappear. Jones and Wechsler (31) have made a study of this "fatigue" mechanism. The observations just mentioned suggested the possibility of a mechanism working in the opposite direction and an investigation of the matter was undertaken. The presence of any facilitation is difficult to determine since it may be present, yet masked by "fatigue" so that reflexes appear smaller. Further it seems that facilitation cannot be expected to occur invariably as the result of a strong stimulus. On a number of occasions it was observed that a subject coming to the experiment in an excited condition, or after violent physical exercise had a low resistance and lively reflex to begin with, and could not be made to show any facilitation or large resistance drop. This, of course, is about what one would expect, for if the subject had been stimulated strongly previous to the experiment he would react maximally at the start and could do no more.

Consequently the best method of attack appeared to be that of comparing a subject's facilitation or lack of it with the amount of resistance drop which he underwent during strong stimulation. Measurements were taken from two experimental groups. The first was the group used in the comparison of latent times to light and sound and long and short stimuli. The procedure was such as to make possible the study of facilitation, since the spectrum was given three times, the sound three, and the spectrum three, all at minute intervals. These reactions were recorded photographically. A second group was given the same sort of procedure, using the flash of a neon bulb for the weak stimulus and a buzzer for the strong. These stimuli were given at 30 second intervals, and only two sounds were given in succession instead of three. Reactions were read from the milliammeter. Current in the first series was 0.3 ma and in the second 0.2 ma. All reactions were expressed in ohms.

The first experimental group consisted of fourteen individuals, and the second of fifteen. In both experiments the average reaction of each subject to the first three weak stimuli was subtracted from his average reaction to the second three, and

the average reaction to the second three subtracted from that to the third three. Total resistances were treated similarly, except that the subtraction was performed in the other direction. If resistance rose or reflex decreased the resulting difference, therefore, had a negative sign. Each subject would ordinarily yield two pairs of readings on resistance—reflex change.

The average resistance drop for all subjects who showed an actual increase in reflexes after strong stimulation was compared (Tables XX and XXI) with the average resistance drop of those who did not show such an increase. It is clear that when the reflex increases, the resistance has dropped sharply. To test the converse of this proposition it would not be possible to consider reflexes when resistance increased and when it decreased, since it almost invariably decreases somewhat, probably on account of the passage of current. Therefore, the average resistance drop for each group of strong stimuli was computed, and those reflexes corresponding to a drop less than average were compared with those corresponding to a drop greater than average.

For purposes of this comparison reflexes are best expressed

TABLE XX. COMPARISON OF REFLEX AND RESISTANCE CHANGES. First Experimental Group.

Per cent change in reflex when resistance drop is greater than average—(first and second reflex series)	+ 42.3
P.E. of above average	23.
Per cent change in reflex when resistance drop is less than average—(first and second reflex series)	— 60.
P.E. of above average	19.
Diff. of above averages	102.3
P.E. Diff.	30.
$\frac{D}{P.E.}$	3.4
Per cent change in reflex when resistance drop is greater than average—(second and third reflex series)	+126.
P.E. of above average	23.
Per cent change in reflex when resistance drop is less than average—(second and third reflex series)	— 61.
P.E. of above average	21.
Diff. of above averages	187.
P.E. Diff.	31.
$\frac{D}{P.E.}$	6.
Average resistance drop when reflex increased	2760 ± 380
Average resistance drop when reflex decreased	700 ± 210
Diff.	2060 ± 430
$\frac{D}{P.E.}$	4.75

TABLE XXI. COMPARISON OF REFLEX AND RESISTANCE CHANGES. Second Experimental Group.

Per cent change in reflex when resistance drop is greater than average—(first and second reflex series)	+ 43.3
P.E. of above average	13.8
Per cent change in reflex when resistance drop is less than average—(first and second reflex series)	— 55.9
P.E. of above average	7.1
Diff. of above averages	99.2
P.E. Diff.	14.6
$\frac{D}{P.E.}$	7.1
Per cent change in reflex when resistance drop is greater than average—(second and third reflex series)	— 62.4
P.E. of above average	16.3
Per cent change in reflex when resistance drop is less than average—(second and third reflex series)	—104.4
P.E. of above average	14.3
Diff. of above averages	42.
P.E. Diff.	21.6
$\frac{D}{P.E.}$	1.9
Average resistance drop when reflex increased	6250 ± 1540
Average resistance drop when reflex decreased	1190 ± 160
Diff. of above averages	5150 ± 1540
$\frac{D}{P.E.}$	3.3

as percents of the subject's reactivity, since an increase from 50 to 60 ohms may be considered equal to an increase from 500 to 600. It would not be well to use the average of either the first or second groups of reaction compared as a base of percentage because some subjects first give large reactions, diminished in the second group by fatigue, and some give small reactions increased by facilitation in the second group. As a basis of percentage the average of both groups of reactions under consideration was used, since this seems to equalize the increasing and decreasing tendencies. Representing reactions by letters the whole procedure for reflexes amounts to the following expression: $-\frac{a+b+c}{3}+\frac{d+e+f}{3}$ all divided by $\frac{a+b+c+d+e+f}{6}$.

These data from the two experimental groups agree, showing that there is a relationship betweeen a drop in resistance following strong stimulation and the size of subsequent reflexes. A drop in resistance greater than average tends to be followed by a reflex to a weaker stimuli greater than it would otherwise have been.

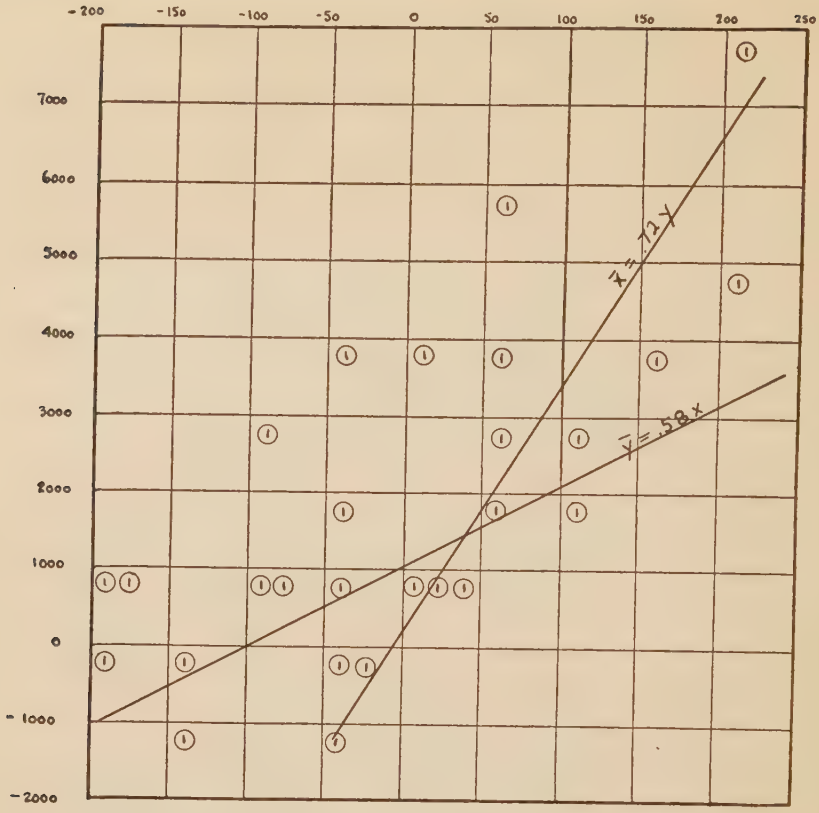


FIGURE 11.
Correlation between Reflex Change (in per cents) and Resistance Drop (in ohms).
First Experimental Group.

The figures suggest that the relationship might be expressed by a correlation. Tables XXII and XXIII give correlations between resistance drop and increase of reflex with the reflexes expressed first as ohms, and then as percents as explained above. Figures 11 and 12 present the distributions for the correlations with the reflex expressed in percents. In view of these correlations one might expect a negative correlation between the reflexes before strong stimulation and the amount of resistance drop produced by it, since subjects who are responding maximally at first would be expected to show only a small drop in resistance. Conversely reflexes to weak stimuli following strong should correlate positively with the change

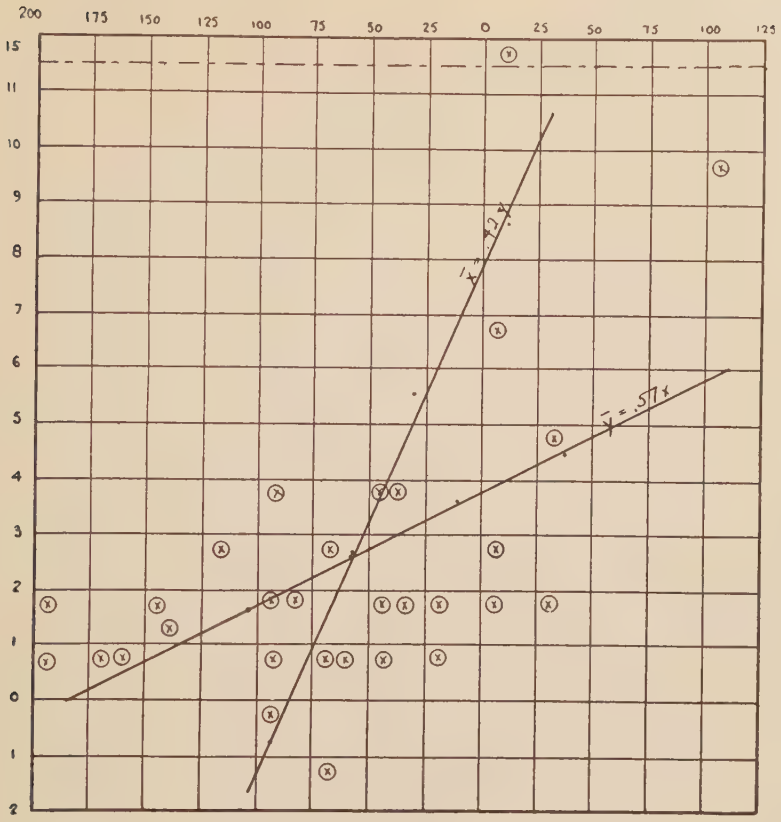


FIGURE 12.

Correlation between Reflex Change (in per cents) and Resistance Drop (in thousands of ohms).
Second Experimental Group.

caused by the strong. These correlations, with the reflexes expressed in percents as before, appear in Tables XXII and XXIII.

Before concluding from these figures it might be well to examine certain possible sources of error. All the correlations are concerned with averages, and most of them with percents.

TABLE XXII. CORRELATIONS SHOWING FACILITATION.
First Experimental Group.

Resistance change X Per cent reflex change.....	+ .653 ±.069
Resistance change X Reflex change ohms.....	+ .456 ± .103
Resistance change X Reflexes preceding (in per cents)..	— .639 ± .075
Resistance change X Reflexes succeeding (in per cents)..	+ .639 ± .075

TABLE XXIII. CORRELATIONS SHOWING FACILITATION.
Second Experimental Group.

Resistance change X Per cent reflex change.....	$+ .505 \pm .078$
Resistance change X Reflex preceding (in per cents)....	$- .636 \pm .073$
Resistance change X Reflex succeeding (in per cents)...	$+ .636 \pm .073$

Since all averages involve the same number of reactions there is no possibility of a correlation of their denominators. The correlations of course may not be taken as applying to individual reactions, but in this case the averages are of as much interest as single reactions. Expressing reactions as percents raises the correlation quite markedly but this cannot be a spurious increase because in no correlation were both variables of a pair divided by the same number. Further, correlations are not introduced by a correlation between resistance drop and the divisor used for putting the reflexes into percents, since these correlations were computed and found to be zero. Insofar as these errors are concerned the correlations appear to be genuine.

Correlations for the second experimental group, it will be observed, are lower than for the first. There are two reasons which may account for the fact. Chiefly it will be noticed in the scatter diagram for the second experimental group that readings tend to fall toward the lower end of both scales. Subjects in this second experiment were much less familiar with the experimental conditions and were consequently of the type which is already reacting maximally at the beginning of the experiment, making both distributions skewed. Another disturbing factor may be the fact that stimulation in the second experiment was every 30 seconds rather than every minute.

These correlations confirm the relationship shown by the differences between averages, that reactivity subsequent to strong stimulation is much affected by the size of the reaction to that strong stimulation.

In order to test whether ordinary resistance drop, independent of strong stimulation, will have the same facilitating effect a third experimental group (twelve subjects) was tested. Procedure in this group was to give three spectrum stimuli at minute intervals, then after a four minute interval three more, another four minute interval and three more. Reactions were recorded photographically. Treating the results in the same

manner as before gives a correlation .17 ± .14 between resistance drop and increase in reflex. When the reflex in a succeeding group shows an actual increase the average resistance drop is 310 ohms; when it shows a decrease the average resistance drop is 1070 ohms. When the resistance drop is greater than the average found in the group as a whole the average percentage change of the second group of stimuli as compared with the first was —48, of the third group as compared with the second was — 8.5, when the resistance drop is less than average the corresponding reflex changes were + 9.9 and — 48.9. In sum, none of the relations found in the first two experimental groups hold for the third in which the sound stimuli were not given. This would mean either that the resistance changes and facilitations of the reflex in the first two groups of subjects are not directly related, but have a common cause, or that resistance variations in the third experimental group were not large enough to produce facilitation.

It may be remarked in passing that each group of responses in the third experimental group shows an average percentage decrease of 33 to 35 as compared with the preceding group of responses, in spite of the four minute rest interval.

During the preceding discussion the resistance drop and the galvanic reaction have been spoken of as though they were quite different phenomena. This, however, may not be. Although one is much larger than the other in this investigation, both are decreases in the apparent resistance of the body. One is small and soon over, the other large and more lasting. In order to compare the course of the long change with the usual small reaction wave and investigate the duration of the long changes two subjects were given single strong stimuli and the course of these reactions and recovery plotted in 30 second intervals. These records are presented in Figures 13 and 14. It will be noticed that during the recovery portion of the curve there are certain reversals which tend to prolong the depression, one curve having so many that recovery was not attained in the time of the record. These are reactions which occurred but are not fully recorded by the plotting method. The stimuli for these are unknown. Reactivity being increased after the large initial drop in resistance, the low resistance of the excited state thus tends to be perpetuated. Aside from these small waves the changes following the large stimuli have the same general form as the reaction waves

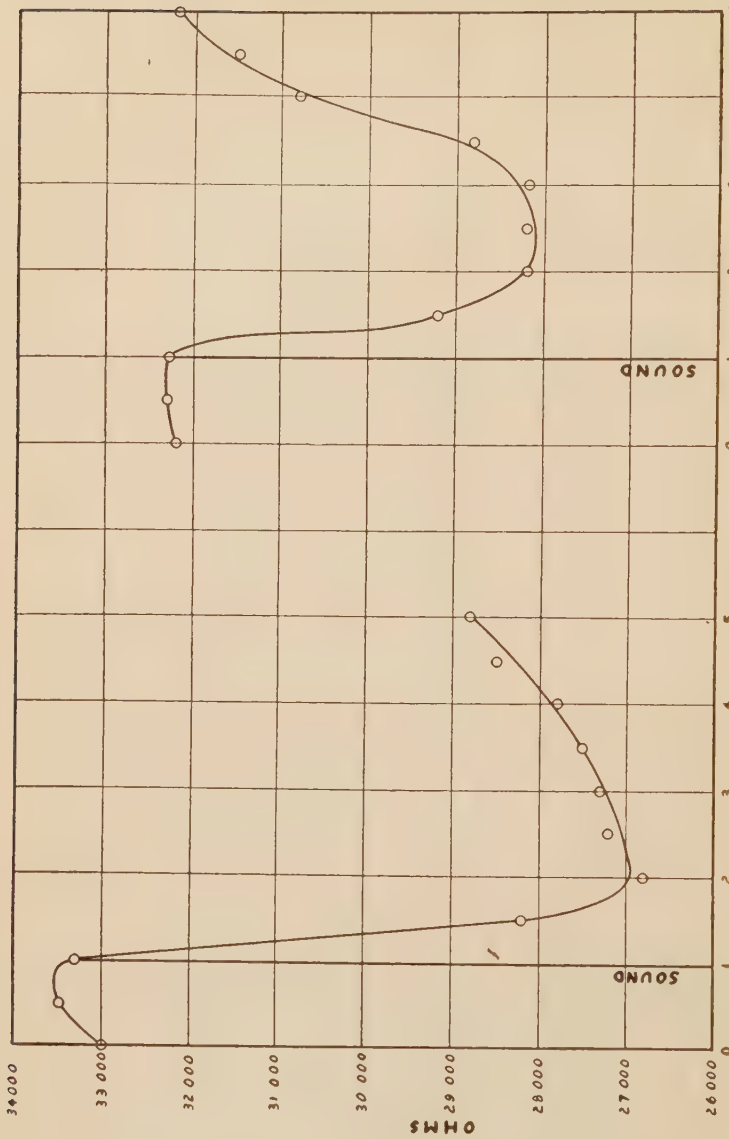


FIGURE 13.

Course of Total Body Resistance after Strong Stimulation. Subject A.

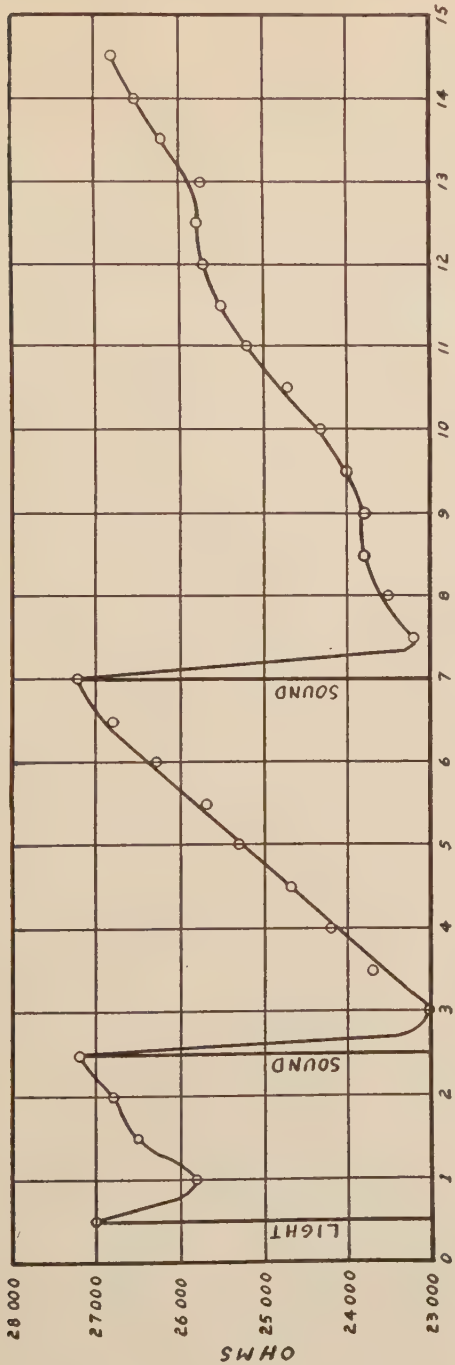


FIGURE 14.

Course of Total Body Resistance after Strong Stimulation. Subject B.

previously analyzed. (According to convention the two are plotted in opposite directions.) It is a fair inference that the two phenomena are large and small samples of the same thing. The statement of the correspondence discussed in this chapter would then be that during recovery from a large and lasting reflex reactivity to other stimuli is heightened, and, within limits, the larger the original reflex the more reactivity is heightened. This relationship may well be the explanation of the disagreement between Smith (42) and Lauer (34). The former found that reactivity correlated negatively with initial total resistance. The latter found a correlation of zero. If one had a group of subjects already facilitated at the beginning, and the other produced facilitation with his stimuli the results would be expected.

It should be noticed that this process of facilitation is not one which replaces the usual "fatigue" mechanism, since in calculation all possible allowance has been made for fatigue. Rather the two act concomitantly.

In search of an explanation for this correspondence it is advisable to review the information on the variations in general level of resistance obtained by the few investigators who have been interested in the matter.

Richter (39) reported a marked drop in resistance caused by local heating and also by exercise. Later (40) he reported a tremendous increase in resistance and disappearance of the reaction in the cat after transection of the spinal column with a drop in resistance and recovery of reaction after several days. Ebbecke (51) found that narcotic drugs raised the bodily resistance and caused the reaction to disappear. Richter (38) seems to have found a rise in resistance and decrease in reaction during sleep, though this is disputed by Landis and DeWick (33). Estabrooks (9) found a rapid mounting of resistance at the onset of hypnosis and in general diminished reflex in the hypnotic state.

These results and those here reported tend to show a negative correspondence between general level of resistance and reactivity under a number of conditions. On the other hand are the results reported in the third chapter of the present monograph and the studies of the reflex under alternating current which find polarization greater and reflex greater at the same time.

One solution of the difficulty would be to suppose that the re-

sistance and reactivity in cases of facilitation are not directly related, but functions of some third variable, for instance a center somewhere in the nervous system which could remain in an excited condition for some time after stimulation. By a tonic discharge it would keep the effector organs in the skin in a partially excited condition. Its threshold to new stimulation might be lowered, or its discharge might in some way serve as reinforcement to a new reaction.

Another alternative would be to suppose that the effector itself is the seat of the process. Once excited it would lag for some time in returning to normal, and in this state somehow be more responsive.

A third alternative would be a combination of the other two, —that the whole pathway is involved. On logical grounds, of course, there is little to be said for the first theory—explaining an observed process by a similar one going on behind the scenes. A stronger objection to it and to the third is the short duration of all known excitation processes in the nervous system, which has been some obstacle in the way of explaining the conditioning of reflexes to stimuli at relatively long temporal intervals. The relative slowness of the galvanic response in reaching its maximum as well as in receding should be considered. If one attributes the slow recession of the reaction wave to a function of the nervous system it is reasonable to suppose that the rise is likewise.

Since the galvanic reaction seems to be the only electrical response so far reported with has such a slow rise and long duration, a theory which attributes long after effects to the reacting organ has a certain attractiveness.

A tentative theory of such a process may be developed from the facts of electrotonus. As pointed out in Chapter III there is reason to believe that the reflex occurs chiefly at the cell membranes toward the anode. In nerves it is rather well established (Höber 27) that the threshold of stimulation is raised when polarization at the anode is increased. Recently Ebbecke (7) has shown the same to be true of the "local galvanic skin reaction." The threshold once being overcome it would be expected that a larger reaction would result. In a case in which a subject presents an initially high resistance, it may be supposed, then, that there is much polarization and consequently a general rise in threshold. Weak stimuli would be able to pass the thresholds of only a few cells, producing

a small aggregate reaction. A strong stimulus, such as the sound used, would, however, be able to pass the threshold of a large number of cells, producing a reaction of great magnitude, such as those plotted in the above figures. Since the reflex is depolarization, those cells which reacted are left in a condition of less resistance and lowered threshold. While they would not be capable of such large reactions, they would be readier to produce small ones, and the weak stimuli which ensued would evoke greater aggregates than they previously did.

Such a theory reconciles the findings in this section with the results reported on the effect of varying currents where it was found that increased polarization increased the actual size of the reflex. In that experiment all reactions were probably maximal, or nearly so, analogous to the reactions to strong stimuli in the present experiment. In fact for the first experimental group in each investigation, the standard stimulus for the current research was identical with the "strong" stimulus used in the facilitation research.

Such a theory carries out Gildemeister's guess (21) that the effector of the galvanic reaction has more importance in determining the nature of the reaction than is usually supposed for effector organs. It is so unusual, however, that one hesitates to adopt it off hand, for if the organ is the determining factor in such facilitation and, possibly in other processes, it usurps most of the functions of the "higher centers." It is possible, of course, that both the neural and effector organ theories are true. The sympathetic ganglia and nerves leading to the effector organs may have some of the same characteristics as the organs.

VI

VARIABILITY OF REFLEX AND RESISTANCE

It is of some interest to know over what magnitude the galvanic reflex may range and how much of that range my be covered by a given individual. Data on the actual variations in size of the phenomenon expressed in electrical units are relatively rare in the literature, but valuable in indicating the number and importance of the influences operating upon it.

Data used to compute measures of variability were taken from the second experimental group described in Chapter III and the second group in Chapter V, records in both cases being taken from the milliammeter readings.

Table XXIV summarizes the averages, standard deviations and coefficients of variability for the reaction to the first three stimuli, these being lights presented to the group described in Chapter V.

TABLE XXIV. VARIABILITY OF THE REFLEX IN A GROUP.
(Standard Stimulus.)

	Average	σ	*V*
1st stimulus	1099 ohms	1279	116
2nd stimulus	268	580	216
3rd stimulus	190	230	121

One factor affecting variability is of course the stimulus, but with this and measuring current held constant the standard deviation is somewhat greater than the average. Evidently there are many factors other than the nature of the stimulus entering into the response.

In this connection should be considered the work of Wechsler and Jones (48) who conclude that the reaction is "specific to the stimulus." This need not be taken to mean that the reaction is specific only to the stimulus; but to indicate that the stimulus is one factor influencing the response. Arguing from correlation increasing with increasing similarity of stimuli, they are inclined, however, to believe that individual differences are relatively unimportant. Their work is difficult to evaluate because of the technique used, particularly since similar stimuli were placed near together.

Table XXV compiled from reactions of individuals to the standard sound stimulus in the experiment on the effect of current shows that individuals tend to react at different levels rather than range over the whole distribution.

TABLE XXV. VARIABILITY OF THE REFLEX TO A STANDARD STIMULUS.

	Current	*Average*	σ	*V*
Subject 1.	.1 ma.	859	1172	130
.....	.3	555	523	94
.....	.5	528	334	63
Subject 2.	.1	1595	1399	87
.....	.3	1051	861	81
.....	.5	864	490	57
Subject 3.	.1	382	367	93
.....	.3	249	224	90
.....	.5	223	241	108
Subject 4.	.1	1296	786	61
.....	.3	522	586	113
.....	.5	661	446	68
Subject 5.	.1	478	650	136
.....	.3	386	352	91
.....	.5	381	315	83
Subject 6.	.1	167	164	99
.....	.3	59	93	157
.....	.5	65	84	124
Average				97

This finding is not directly opposed to that of Wechsler and Jones, since the individuals here concerned might conceivably fall into different order with responses to different stimuli. This same Table XXV yields data on the long run variability one may expect to encounter in a similarly conducted experiment in which one wishes to find differences in reactions to two different stimuli, or two different contributing conditions. The general average indicates that the relative variability is nearly as great for the individual as for the group represented in Table XXIV.

From this it may first of all be concluded that the reaction is difficult to work with in the present state of knowledge because so many readings are necessary to secure a reliable difference. Assuming, as seems to be the case, that the coefficient of variability remains the same, it is possible to predict how many readings on a subject (or on a group) would be necessary to establish a reliable difference of a given magnitude. Let a and b be the two averages between which it is desired to establish a difference. To be conventionally re-

liable the difference, a—b, should be four times its P.E. With a V of 97 the P.E. of the difference, by substituting in the usual formula, is

$$\sqrt{.675\ \frac{.97a^2}{N} + .675\ \frac{97b^2}{N}}$$

if the two series are uncorrelated. Setting the two expressions equal to one another, solving for N, and letting $d = \frac{a—b}{a}$ the equation becomes $N = \frac{10.4d^2 — 20.8d + 20.8.}{d^2}$

In this equation d is the difference between the two averages expressed as a fraction of the first. Therefore Table XXVI may be computed from the equation showing the number of readings necessary to get a difference four times its P.E. when the difference expected is a given percent of the first average. The number of readings is that necessary for each of the variables. The number of sittings is computed on the basis of four similar readings at each sitting.

TABLE XXVI. NUMBER OF REFLEXES NECESSARY TO ESTABLISH DIFFERENCES.

	Number Reflexes Necessary For Each Condition Compared	*Number Sittings Twelve Reflexes at Sitting*
100 per cent	11	2
50 per cent	54	9
25 per cent	250	42
10 per cent	1880	314

NOTE: This table allows for the effect of varying current, and individual differences but not for fatigue and daily variations.

Not too much weight should be laid on this deduction, but it does give some indication that an experimenter hoping to establish small differences must be prepared for a rather long siege, and it is possible that all factors affecting the reflex are small, though it is to be hoped otherwise.

With such wide variability in the reflex the most necessary contribution to knowledge of the reflex seems to be the discovery of more participating factors which can be controlled experimentally. With an increased knowledge of these factors variability would be lessened and further research rendered less laborious.

TOTAL RESISTANCE VARIATIONS

As might be expected, the variability of total resistance of subjects is considerably less than the variability of the reflex. The reflex itself is, of course, simply a variation of the apparent total resistance, and quite possibly the typical kind of variation. The first statement of this paragraph may mean simply that the reflex is larger with respect to itself than it is with respect to the base from which it varies.

TABLE XXVII. VARIABILITY OF RESISTANCE IN A GROUP.

	Average	σ	*V*
At 1st stimulus	26,400	9300	35
At 2nd stimulus	25,900	8900	34
At 3rd stimulus	25,800	8100	31

TABLE XXVIII. VARIABILITY OF RESISTANCE.

	Current	*Average*	σ	*V*
Subject 1.	.1 ma.	227	88	39
.....	.3	202	62	31
.....	.5	184	26	14
Subject 2.	.1	297	72	26
.....	.3	247	35	14
.....	.5	242	36	15
Subject 3.	.1	248	21	9
.....	.3	207	27	13
.....	.5	194	15	8
Subject 4.	.1	304	47	15
.....	.3	251	40	16
.....	.5	253	25	10
Subject 5.	.1	247	67	27
.....	.3	220	27	12
.....	.5	208	16	8
Subject 6.	.1	276	48	17
.....	.3	238	39	17
.....	.5	220	26	12
Average				16.8

Table XXVII shows the average, standard deviation and coefficient of variability for the resistance of subjects during the first three stimulations (by light) in the facilitation experiment. The variability of individuals (data from research on current) is shown in Table XXVIII. It will be seen that variability of the resistance is roughly one-fifth that of the reflex.

SUMMARY

The investigation was undertaken to determine how far the galvanic skin reaction and bodily resistance are affected by the pecularities of the individual, by certain physical conditions of measurement, by differences in stimuli, and by the previous condition of the subject.

1. An apparatus was devised for obtaining a record, photographic or read, of the reaction without distortion, and for controlling accidental and intentional stimuli to the subject.

2. The galvanic reaction was found to increase in size with measuring current, but not in proportion to the current. This fact was explained by the membrane depolarization theory.

3. The latent period of the reaction was found to be a function of the stimulus. The stronger stimulus gives a shorter latent period. There are indications of individual differences in latency.

4. There is a low negative correlation between latency and amplitude of response with stimulus and subject the same.

5. A 25 per cent variation in the duration of the stimulus has little effect on the latent period.

6. Latent time increases with time after a long series of reactions.

7. The theory was suggested that the observed facts of latent period may be explained as conditioned upon variations in frequency of nervous conduction, or upon inertia of the reacting organ.

8. Stronger stimuli give reactions of longer rising period.

9. There is a moderately high correlation between rise and amplitude of response. It was suggested that this relation is produced by the characteristics of the reacting organ.

10. It was found that strong stimuli have a tendency to lower skin resistance over a considerable period of times and increase responsiveness to weaker stimuli. A theory was suggested which makes the lowered resistance the factor which causes reactivity to be higher.

11. Variability of the reflex in a group of individuals reacting to the same stimulus was found to be over 100.

12. One individual's reactions to the same stimulus will not vary over the whole range but still have a V of about 100.

13. Bodily resistance has a V about one-sixth of that for reflexes.

BIBLIOGRAPHY

1. Aveling & McDowall. Effect of circulation on electrical resistance of the skin. Jour. of Physiol., 1925, 60, 316.
2. Darrow, C. Sensory, secretory, and electrical changes in the skin following bodily excitation. Jour. Exp. Psychol., 1927, 10, 193.
3. Darrow, C. The galvanic skin reflex and finger volume changes. Am. Jour. Physiol., 1929, 88, 219.
4. David, E. Über die sekundär elektromotorische Eigenschaften der menschlichen Haut. Pflüger's Arch., 1922, 195, 101.
5. Davis, R. C. A vacuum tube for stabilizing current during measurement of the galvanic reflex. Am. Jour. Psychol., 1929, 41, 474.
6. Dunlap, K. Psychogalvanic, circulatory, and respiratory phenomena. Psychol. Bull., 1913, 10, 142.
7. Ebbecke, U. Über elektrische Hautreizung und Electrotonus, Pflüger's Arch., 1926, 211, 761.
8. Einthoven & Roos. Über Widerstand und Potentialdifferenz bei dem psychogalvanischen Reflex. Pflüger's Arch., 1921, 189, 126.
9. Estabrooks, G. H. The psychogalvanic reflex in hypnosis. Jour. Gen. Psychol., 1930, 3, 150.
10. Foa, C. & e Peserico, E. Le vie riflesso neurogalvanico. Arch. di Fisiol., Firenze, 1923, 21, 119.
11. Gasser & Erlanger. A study of action currents of nerves with the cathode ray oscillograph. Am. Jour. Physiol., 1922, 62, 496.
12. Galler, H. Über den elektrischen Leitungswiderstand der tierischen Körpers. Pflüger's Arch., 1912, 199, 156.
13. Gildemeister, M. Der sogennante psycho-galvanische Reflex und seine physikalisch-chemisch Deutung. Pflüger's Arch., 1915, 162, 489.
14. Gildemeister, M. Über elektrischen Widerstand, Kapazität und Polarisation der Haut. I. Versuche an der Froschhaut. Pflüger's Arch., 1919, 176, 155.
15. Gildemeister, M. & Kaufhold, R. Über das elektrische Leitungsvermögen der überlebende menschilchen Haut. Pflüger's Arch., 1920, 179, 154.
16. Gildemeister, M. Zur Theorie der sekundär elektromotorischen Eigenschaften der menschlichen Haut. Pflüger's Arch., 1922, 195, 112.
17. Gildemeister, M. Der galvanische Hautreflex als Teilerscheinung eines allgemein autonomes Reflexes. Pflüger's Arch., 1922, 197, 432.
18. Gildemeister, M. Zur Physiologie der menschlichen Haut II. Über die Messung des galvanischen Hautreflexes mit Spulengalvanometern. Pflüger's Arch., 1923, 200, 254.
19. Gildemeister, M. & Ellinghaus, J. Zur Physiologie der menschlichen Haut III. Über die Abhangigkeit des galvanischen Hautreflexen von der Temperature der Haut. Pflüger's Arch., 1923, 200, 262.
20. Gildemeister, M. Zur Physiologie der menschlichen Haut IV. Über Zellpermeabilität und Erregung. Pflüger's Arch., 1923, 200, 278.
21. Gildemeister, M. Handbuch der normalen und pathologischen Physiologie, (Bethe und and.) 1926.
22. Gildemeister, M. Über elektrische Schwingung hervorgerufen durch die Hautkapazität. Pflüger's Arch., 1929, 219, 82.
23. Gildemeister, M. Über elektrischer Widerstand, Kapazität und Polarisation der Haut. II. Mitteilung, Menschliche Haut. Pflüger's Arch., 1929, 219, 89.

24. Godefroy, J. C. Het getransformeerde psychogalvanische verschijnsel. Ned. Tidshr. v. Geneesk, 1920, 1, 2.
25. Grünbaum, A. A. Het psychogalvanisch reflexverschijnsel en zijn psychodianostische waarde. Ned. Tijdschr. v. Geneek, 1920, 1, 1044.
26. Hathaway, S. R. A comparative study of psychogalvanic and association time measures—a new psychogalvanic apparatus. Jour. of Appl. Psychol., 1929, 13, 632.
27. Höber, R. Physikalische Chemie der Zelle und die Gewebe. 1926.
28. James, H. E. O. & Thouless, R. H. A note on the effect of polarization in psychogalvanic reflex experiments. Brit. Jour. Psych. (Gen.), 1926, 17, 49.
29. Jeffress, L. Galvanic phenomena of the skin. Jour. Exp. Psychol., 1928, 11, 130.
30. Johnson, H. M. Noise, a social problem. Harper's Mag., 1929, 159, 561.
31. Jones, H. E. & Wechsler, D. Galvanometric technique in studies of association. Am. Jour. Psychol., 1928, 50, 607.
32. Kelley, T. L. Statistical method. 1923.
33. Landis, C. & DeWick, H. Electrical phenomena of the skin. Psychol. Bull., 1929, 26, 64.
34. Lauer, A. H. Reliability of the galvanic reflex. Am. Jour. Psychol., 1929, 41, 263.
35. Lullies, H. Über die Polarisation im Geweben I. Pflüger's Arch., 1929, 221, 296.
36. Prideaux, E. Expression of emotion in cases of marked disorder as shown by the psychogalvanic reflex. Brit. Jour. Psychol. (Med.), 1921, 2, 23.
37. Radeki. Recherches experimentals sur les phenomenones psychoelectrique. Arch. de Psychol., 1911, 11.
38. Richter, C. P. Significance of the changes in the electrical resistance of the body during sleep. Proc. Nat. Acad. Sci. 1926, 12, 214.
39. Richter, C. P. Physiological factors involved in the electrical resistance of the skin. Am. Jour. Physiol., 1929, 88, 596.
40. Richter, C. P. The galvanic skin reflex in spinal animals. Proceedings IX Int. Cong. Psychol., 357.
41. Schilf & Shubert. Über das sogenannte psychogalvanische Reflexphanomen beim Frosch und seine Beziehung zum vegetative Nervensystem. Pflüger's Arch., 1922, 195, 75.
42. Smith, W. W. The measurement of emotion. 1922.
43. Strohl, A. Sur la resistance electrique apparente du corps humain pour les courants de faible durée. Comp. Rend. Soc. Biol., 1921, 85, 125.
44. Syz, H. Psychogalvanic studies of sixty-four medical students. Brit. Jour. Psychol. (Gen.), 1026, 17, 54.
45. Sung Sheng & Lehman. Die Einfluss verscheidener Spannung auf den galvanische Hautreflex. Pflüger's Arch., 1927, 197, 437.
46. Thouless, R. H. Magnitude of the psychogalvanic reflex phenomenon in alternating current circuits and direct currents of high E. M. F. Proceedings, IX Int. Cong. Psychol., 432.
47. Wechsler, D. The measurement of emotional reactions. Arch. Psychol., 76, 1925.
48. Wechsler, D. and Jones, H. E. A study of emotional specificity. Am. Jour. Psychol., 1928, 40, 600.
49. Wertheim-Salomonson. Bijdrage tot die kennis van het psychogalvanischen reflex. Versl. Wis en Naturk. Afd. kon Akad. v. Wetensch. D XXIV 2, 997.

50. Erlanger and Gasser. The action potential in fibers of slow conduction in spinal roots and somatic nerves. Am. Jour. Physiol., 1930, 42, 43.

51. Ebbecke, U. Der Psychogalvanische Reflex in der Narkose, Proceedings IX Int. Cong. Psychol., 1930. 155.

52. Davis, R. C. and Porter, J. M., Jr. A Measuring Device for the Galvanic Reflex. Jour. of Gen. Psychol. (to be published).

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